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Final

LANDAU ASSOCIATES, INC.

Final Treatment & Discharge Plan

Phase II Remedial Design/Remedial Action Colbert Landfill Spokane, Washington

2/26/93

February 26, 1993

Prepared for

Spokane County, Washington

Prepared by

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February 26, 1993

Mr. Michael Kuntz
Site Cleanup Section
Washington State Department of Ecology
Olympia, WA 98504-7600

RE: SUBMITTAL OF THE FINAL PHASE II TREATMENT AND DISCHARGE PLAN FOR THE COLBERT LANDFILL RD/RA PROJECT

Enclosed are three copies of the Final Phase II Treatment and Design Plan (Final Plan) for the Colbert Landfill Remedial Design/Remedial Action Project (Project). This Final Plan was prepared for Spokane County by Landau Associates, Inc. to fulfill the Project Consent Decree submittal requirements.

The Final Plan represents the last 60 percent design submittal. Ecology and EPA comments on the Preliminary Treatment and Discharge Plan, contained in Ecology's April 28, 1992 letter, are addressed in the Final Plan, except that most of the Ecology comments related to Phase II effluent discharge will be addressed separately (as previously discussed with Ecology and EPA).

As identified in the Schedule for Submittal of Deliverables, Ecology and EPA comments on the Final Plan should be provided to Spokane County within 30 days of plan submittal. Because of schedule delays that have occurred over the past year, it is very important to the success of the Project that regulatory review be completed within the allocated period. Please contact Dean Fowler (Spokane County) or myself, should any questions arise during your review or if there is anything else we can do to assist you in your review of the Final Plan.

LANDAU ASSOCIATES, INC.

By:

Larry Beard

Lawrence D. Beard, P.E.
Project Manager

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02/26/93 COLBERT\KUNTZ.LET

cc: Neil Thompson, EPA (5 copies)
Dean Fowler, Spokane County (2 copies)

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1.0 INTRODUCTION

This Final Phase II Treatment and Discharge Plan (Final Plan) presents the final design criteria and preliminary design for the groundwater treatment and discharge systems for the Colbert Landfill Phase II Remedial Action Project (Project). The Final Plan is submitted by Spokane County in fulfillment of Project Consent Decree (U.S. District Court 1988) requirements for this document, and incorporates U.S Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) review comments on the Preliminary Treatment and Discharge Plan (Landau 1992a).

This Project will implement extraction, treatment, discharge, and monitoring systems for contaminated groundwater at the Colbert Landfill Superfund Site. The remedial action elements addressed in this Plan include the groundwater treatment facility, which utilizes air stripping with supporting scale control chemical addition, and the groundwater discharge system, which includes the pipeline network for conveyance of groundwater from the 10 extraction wells to the treatment facility, and the discharge pipeline which conveys treated groundwater to the Little Spokane River.

This Final Plan is divided into five main sections. Section 1.0 provides introductory information including Project background; general site conditions; Project objectives; and Phase II scope, organization and responsibilities, and schedule. Section 2.0 presents the final basis of design for the groundwater treatment facility, including Consent Decree effluent quality requirements for treated groundwater; final design criteria for influent groundwater characteristics from the planned extraction well system, that incorporates information developed during the ongoing Phase II well construction program; establishment of final design criteria for the air stripping system; and selection of the scale control processes to be implemented. Section 3.0 presents the final design criteria for the groundwater discharge system, including establishment of the final flow network for the piping; selection of pipeline sizes and materials of construction; and establishment of design criteria for appurtenant pipeline facilities. Section 4.0 presents the implementation and quality assurance procedures for Phase II construction. Section 5.0 presents estimated effluent water quality criteria and identifies remaining National Pollutant Discharge Elimination System (NPDES) issues.

This Final Plan is intended as a stand-alone document for the Phase II treatment and discharge system basis of design, and incorporates the results of recently developed site characterization studies and design analyses. Key supporting reference documents include the

Project Consent Decree, which establishes legal requirements for the Project; the Phase I Engineering Report (Landau Associates 1991) which presents the results of the Phase I site characterization, aquifer testing, and groundwater treatment pilot testing programs; the Final Phase II Extraction Well Plan, which presents the bases of design for the groundwater extraction well system (including the groundwater extraction rates and water quality characteristics used as design criteria for the treatment and discharge systems).

This Final Plan represents the 60 percent design submittal for the Phase II treatment and discharge systems. Due to the schedule impacts resulting from additional NPDES evaluation and testing required by Ecology in order to finalize this plan, the Phase II Preliminary Plans and Specifications (90 percent design) is being submitted concurrently with this Final Plan. Subsequent submittals planned at this time include the Final Phase II Plans and Specifications, and the Phase II Construction Documentation Report. The Air Stripping System Procurement Specification which was included and received regulatory review as part of the Preliminary Treatment and Discharge Plan (Landau Associates 1992a), was removed from this Final Plan, and will be submitted under separate cover as part of the Final Phase II Plans and Specifications.

1.1 PROJECT BACKGROUND

The Colbert Landfill (Landfill) is an inactive 40-acre municipal solid waste landfill located approximately 15 miles north-northeast of Spokane, WA, and 2.5 miles north of Colbert, WA, as shown on the Regional Location Map (Figure 1-1). The Landfill operated from 1968 until 1986, when it became filled to capacity with municipal and commercial waste.

Groundwater in the vicinity of the Landfill is contaminated with chlorinated organic solvents. At least part of this contamination has been traced to spent solvents that were disposed of at the Landfill. Solvents were reportedly disposed of at an average rate of several hundred gallons per month for a number of years, and primarily consisted of 1,1,1-trichloroethane (TCA) and methylene chloride (MC). Other organic solvents were also detected in groundwater near the Landfill, including trichloroethylene (TCE), tetrachloroethylene (PCE), 1,1-dichloroethylene (DCE), and 1,1-dichloroethane (DCA). These six chlorinated organic solvents are referred to as the "Constituents of Concern."

In 1980, nearby residents complained to the Eastern Regional Office of Ecology about disposal practices at the Landfill. State and county officials, led by the Spokane County Utilities Department, initiated an investigation into complaints of groundwater contamination in the area by sampling nearby private wells. The results of this initial investigation indicated that some of these wells were contaminated with TCA. In August 1983, EPA placed the Colbert Landfill on its National Priorities List (NPL).

Several studies of the Landfill were conducted since 1980, including the 1987 Remedial Investigation/Feasibility Study (RI/FS; Golder Associates 1987a,b). The purpose of the RI/FS was to determine the nature and extent of contamination caused by the release of chemicals from the Landfill (and the Old Township Dump) and to evaluate potential remedies. The RI determined that the two primary aquifers in the Landfill vicinity (the Upper and Lower Sand/Gravel Aquifers), and a low-productivity aquifer to the east of the Landfill (Weathered Latah/Basalt Aquifer) are contaminated with some or all of the Constituents of Concern. The FS recommended a pump and treat remedy to address this groundwater contamination.

EPA released its Colbert Landfill Record of Decision (ROD) for public comment in September 1987 (EPA 1987). The remedial action site (Site) is defined in the ROD as the area of potential impact surrounding and including the Landfill, as shown on Figure 1-1. Based on recommendations in the FS, the ROD provides for a performance-based remedial action, consisting of a groundwater pump and treat system. Project performance criteria for the Constituents of Concern are presented in the ROD (Performance Standards), and are shown in Table 1-1. These Performance Standards establish the level of treatment for extracted groundwater and define the maximum constituent concentrations that must be achieved for completion of the remedial action.

Although some flexibility is allowed in the remedial approach, the remedial action specified in the ROD provides for a groundwater extraction system, a treatment system, and a discharge system. The ROD subdivides the extraction system into the following three pumping systems:

- The South Interception System, which will consist of a series of extraction wells installed to intercept the contaminant plume in the Upper Sand/Gravel Aquifer south of the Landfill
- The West Interception System, which will consist of a series of extraction wells installed to intercept the contaminant plume in the Lower Sand/Gravel Aquifer west of the Landfill
- The East Extraction System, which will consist of extraction wells installed in the Lower Sand/Gravel and Latah/Basalt Aquifers near the Landfill for source control.

The ROD specifies that extracted groundwater will be treated using air stripping to reduce Constituents of Concern in groundwater to the Performance Standards. ROD-specified discharge options for treated water include the Little Spokane River, Deep Creek, and subsurface infiltration.

Subsequent to implementation of the ROD, a Consent Decree for the Colbert Landfill (U.S. District Court 1988) was negotiated between the EPA and Ecology (government plaintiffs), and Spokane County and Key Tronic Corporation (potentially responsible parties). By this action, the County agreed to implement the EPA-selected pump and treat remedy in accordance with the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) requirements and the State of Washington Hazardous Waste Cleanup Act, codified as Chapter 70.105B RCW.

A scope of work (SOW) to address groundwater contamination emanating from the Landfill is presented in Appendix B of the Consent Decree (U.S. District Court 1988). The SOW specifies the bases for design, design criteria, and criteria for adjustment and modification of the pump and treat system if the performance criteria are exceeded during operation of the remedial action. Because of the difficulties in accurately quantifying MC and DCE at their Performance Standard concentrations, alternative criteria (Evaluation Criteria) were developed in the SOW for assessing performance of Project interception, treatment, and discharge systems, and are presented in Table 1-1.

It was recognized during development of the Consent Decree that available data were inadequate to design the selected remedial action. Consequently, the Project is being implemented in phases. Phase I activities were completed in 1991 and included a number of activities. Thirty groundwater monitoring wells were constructed at 19 locations for additional hydrogeologic and contaminant distribution characterization. Four pilot extraction wells were constructed for aquifer performance (pumping) tests and as source wells for groundwater treatability studies. A pilot air stripping tower was constructed to treat extracted groundwater from pumping tests and for groundwater treatability studies. A discharge system, including piping and outfalls, was constructed to convey water from the pilot extraction wells to the pilot treatment facility and from the treatment facility to the effluent discharge locations. An onsite meteorological station was also constructed to collect meteorological data. The locations of groundwater monitoring wells and pilot extraction wells constructed during Phase I are shown on Figure 1-2.

Phase I activities were completed in July 1991; Phase I results are provided in the Phase I Engineering Report (Landau Associates 1991). A conceptual design for the Phase II interception/extraction, treatment, and discharge systems is presented in the Phase I Engineering Report.

Phase II design, including the treatment and discharge system designs presented in this Final Plan, are largely based on the results of Phase I data and analyses. However, further aquifer characterization is being accomplished during the Phase II well construction program, which was started in September 1992 and is ongoing as of the date of this Final Plan. This additional aquifer characterization has resulted in modifications to the extraction systems described in the Preliminary Plan (Landau Associates 1992a), and ongoing activities may result in changes to the extraction systems described in this Final Plan. Further changes (if any) will be implemented with the review and concurrence of EPA and Ecology.

1.2 SITE CONDITIONS

The Landfill is located on a plateau that is bounded on the west by a steep slope descending toward the Little Spokane River and on the east by low granite and basalt hills. Surface drainage is to the west, toward the Little Spokane River. The climate is characteristic of eastern Washington, with temperatures ranging from typical average summer highs of 83°F to average winter lows of 23°F. The relatively low annual precipitation of approximately 17 inches falls mainly during the winter months of November through February (NOAA 1985).

1.2.1 Hydrogeologic Conditions

The geology of the Landfill area consists of a series of glacially and fluvially derived materials deposited on an eroded landscape of clays, basaltic lava flows, and granitic bedrock. The primary stratigraphic units (layers), from youngest to oldest (i.e., from the top down), are:

Unit A	Upper Sand/Gravel Unit
Unit B	Lacustrine Unit
Unit C	Lower Sand/Gravel Unit
Unit D	Latah Formation
Unit D_1	Weathered Latah Subunit
Unit E	Basalt Unit
Unit F	Granite Unit.

A generalized east-west profile of these units based on Phase I data is shown on Figure 1-3. Figures 4.1 through 4.9 of the Phase I Engineering Report (Landau Associates 1991) provide more detailed geologic cross sections of the Landfill vicinity.

The hydrogeologic system in the Landfill vicinity is characterized in the Phase I Engineering Report (Landau Associates 1991) as containing four aquifers (two primary and two secondary) and three aquitards:

- The Upper Sand/Gravel Unit (Unit A) forms the Upper Sand/Gravel Aquifer when underlain by the Lacustrine Unit (Unit B), and is considered a primary aquifer.
- The Lacustrine Unit (Unit B) is the low-permeability unit that separates the Upper and Lower Sand/Gravel Units and is referred to as the Lacustrine Aquitard. The Lacustrine Aquitard contains water-bearing sand layers and, based on water elevation data, some of the shallow sand layers appear to be in direct hydraulic connection with the Upper Sand/Gravel Aquifer.
- The Lower Sand/Gravel Unit (Unit C) forms the Lower Sand/Gravel Aquifer, which is the second primary aquifer, and the regional aquifer for the Site.
- The Latah Formation (Unit D), and the Weathered Latah Subunit (Unit D_1), serve as the aquitard underlying the Lower Sand/Gravel Aquifer at most locations and (in combination) are referred to as the Latah Aquitard. However, some low-yield private wells are installed in the Latah Aquitard to the east of the Landfill, where the Upper and Lower Sand/Gravel Aquifers are not present.
- The Basalt Unit (Unit E) forms a secondary aquifer interbedded with the Latah Aquitard, and is referred to as the Basalt Aquifer.
- The Granite Unit (Unit F) serves as the lower boundary (aquitard) to the regional flow system, although some low-productivity wells are installed in the upper portion of this unit.
- The Fluvial Unit associated with the Little Spokane River forms the Fluvial (secondary) Aquifer. The Fluvial Aquifer may be in direct hydraulic connection with the Lower Sand/Gravel Aquifer, but piezometric and contaminant migration data [as discussed in the Phase I Engineering Report (Landau Associates 1991)] suggest that it be treated as an independent hydrogeologic unit for the purposes of this Project.

Units C, D, E, and F are collectively referred to as the "Lower Aquifers" for evaluating regional groundwater flow and contaminant distribution, although the Lower Sand/Gravel Aquifer (Unit C) appears to be the only one of these units capable of sustained yield at significant discharge rates.

The Upper Sand/Gravel Aquifer is unconfined, with a depth to water about 90 ft below ground surface in the Landfill vicinity. The thickness of the Upper Sand/Gravel Aquifer varies from about 8-20 ft along its north-south trending centerline, and decreases as it extends toward the western bluff and eastern hills. Upper Sand/Gravel Aquifer groundwater flow is predominantly toward the south with velocities ranging from about 5-7 ft/day (Landau Associates 1991). A groundwater elevation contour map for the Upper Sand/Gravel Aquifer is shown on Figure 1-4.

The Lower Sand/Gravel Aquifer is generally confined west of the Landfill and unconfined from the west Landfill boundary to the east. The potentiometric surface of the Lower Sand/Gravel Aquifer is about 180 ft below ground surface, and saturated thickness varies from 0 ft east of the Landfill to over 200 ft near U.S. Highway 2. Groundwater in the Lower Sand/Gravel Aquifer flows predominantly towards the west at velocities ranging from about 0.3 to 0.6 ft/day (Landau Associates 1991). However, a lobe of low-permeability Latah Aquitard extends to the west into the Lower Sand/Gravel Aquifer. This lobe forms an east-west trending groundwater divide beneath the southern boundary of the Landfill, and causes constituents that enter the Lower Sand/Gravel Aquifer from the Landfill vicinity to migrate in separate (Northern and Southern) Flow Regimes.

East of the Lower Sand/Gravel Aquifer, groundwater flow occurs primarily as perched groundwater at the Lower Sand/Gravel Unit interface with the underlying Latah Aquitard and within the Basalt (secondary) Aquifer, although some domestic wells are screened within the Latah and Granite Aquitards. Pumping test data and other hydrogeologic information indicate that groundwater extraction east of the Lower Sand/Gravel Aquifer is impracticable because of limited aquifer yield, and may exacerbate the spread of contamination in this area (Landau Associates 1991). A groundwater elevation contour map for the combined Lower Aquifers is shown on Figure 1-5.

A number of hydrogeologic boundary conditions converge in the immediate vicinity of the Landfill:

- The Lacustrine Aquitard pinches out, eliminating the hydraulic separation between the Upper and Lower Sand/Gravel Units
- The Lower Sand/Gravel Unit transitions from unsaturated (to the east) to the primary regional aquifer (to the west)
- A lobe of the Latah Aquitard extends (westerly) into the Lower Sand/Gravel Aquifer, creating an east/west trending groundwater divide near the south edge of the Landfill.

These converging boundary conditions control migration of groundwater (and contaminants) from the Landfill vicinity into, and within, the Lower Aquifers. Groundwater (from beneath the Landfill) enters the unsaturated Lower Sand/Gravel Unit either by lateral flow over the eastern edge of the Lacustrine Aquitard or (possibly) by direct infiltration through discontinuities in the Lacustrine Aquitard. Groundwater migrates vertically within the Lower Sand/Gravel Unit until contacting the upper surface of the Latah Aquitard. Groundwater then flows (as perched groundwater) along the Lower Sand/Gravel Unit and Latah Aquitard contact until it enters the Lower Sand/Gravel Aquifer (Northern or Southern) Flow Regime. A conceptual model of these groundwater flow characteristics is shown on Figure 1-6.

Sections 4.1 and 4.2 of the Phase I Engineering Report (Landau Associates 1991) should be reviewed for a more thorough discussion of Project hydrogeologic conditions.

1.2.2 Constituent Distribution

The Upper Sand/Gravel Aquifer, Fluvial Aquifer, and shallow sand interbeds of the Lacustrine Aquitard are collectively referred to as the Upper Aquifers for assessing the distribution of Constituents of Concern in groundwater. The Lower Sand/Gravel Aquifer, Basalt Aquifer, Latah Aquitard, and Granite Aquitard are similarly referred to as the Lower Aquifers for constituent distribution evaluation. Figures 1-7 and 1-8 show the distribution of the Constituents of Concern for the Upper and Lower Aquifers, respectively. These figures are based on a composite of groundwater quality data collected through 1991, and represent the areal extent over which one or more of the Constituents of Concern were detected and the area over which one or more of the Constituents of Concern exceed the Performance Standards.

Section 4.3 of the Phase I Engineering Report (Landau Associates 1991) should be reviewed for a more thorough discussion of Project water quality conditions.

1.3 PROJECT OBJECTIVES

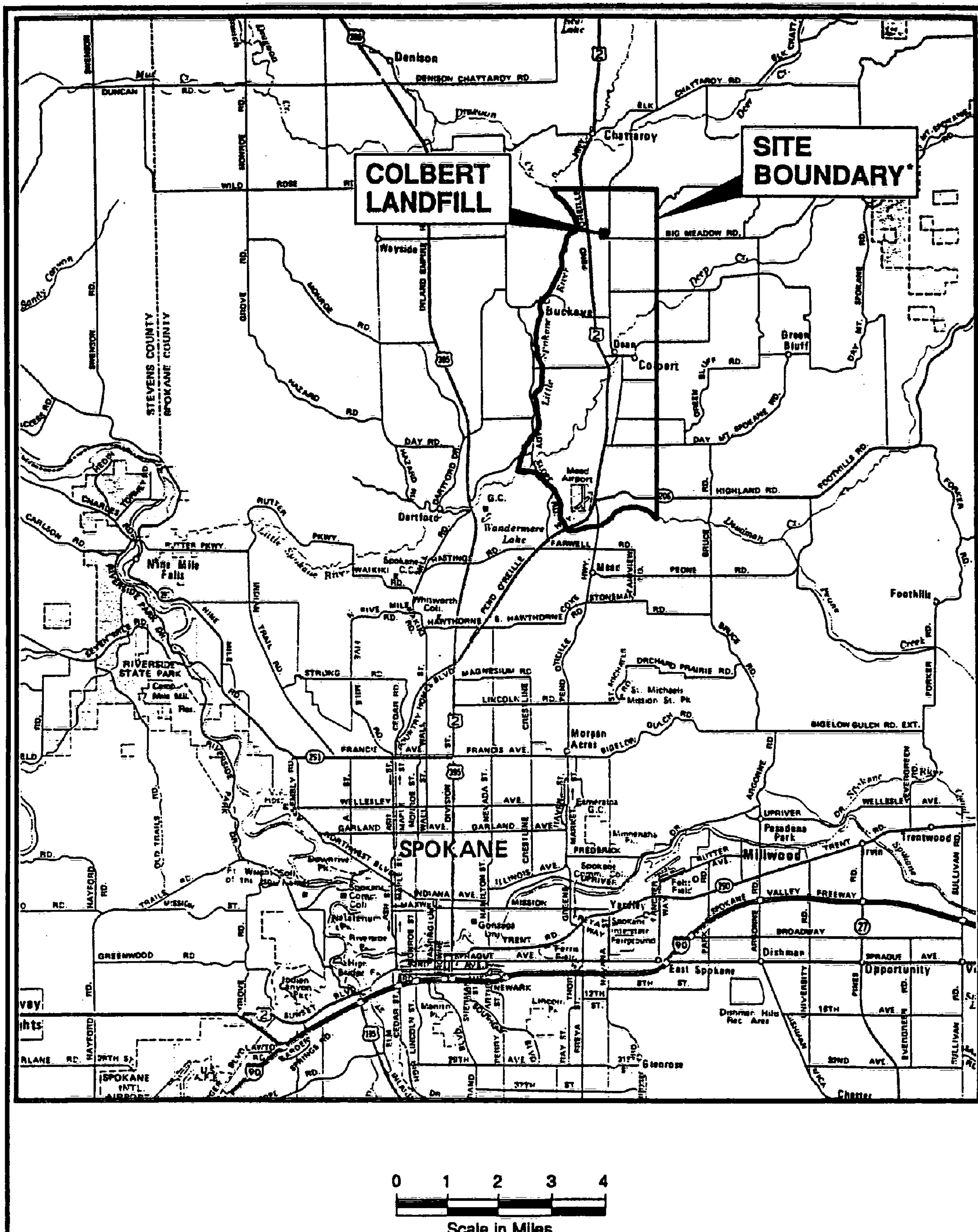
The Project objectives are to: 1) implement aquifer performance and treatability studies to develop design parameters for the final (Phase II) remedial action; 2) perform supplemental characterization (to the RI) of hydrogeologic conditions and the extent of groundwater contamination in the vicinity of the South and West Interception, and the East Extraction Systems; 3) design the final remedial action; and 4) construct the final remedial action and operate the system until the requirements of the Consent Decree are fulfilled.

Objectives 1 and 2 were achieved during Phase I, as documented in the Phase I Engineering Report (Landau Associates 1991). Objective 3 is being implemented and will be documented in Phase II work plans and in the Phase II Plans and Specifications. Phase II 30 percent design was presented in preliminary Phase II work plans. Sixty percent design is presented in the final Phase II work plans, including this Final Plan, the Final Extraction Well Plan (Landau Associates 1992b), and the Final Groundwater Monitoring Plan (Landau Associates 1992c). The Phase II Plans and Specifications represent 90 percent design and are being submitted concurrently with this Final Plan; the Final Phase II Plans and Specifications will be submitted following EPA and Ecology review of the current submittals. Objective 4 will be achieved following EPA and Ecology approval of the Phase II design documents and the construction aspects of this objective will be documented in the Phase II Construction Documentation report.

1.4 PHASE II DESIGN SCHEDULE

The Phase II design process was originally anticipated to require about 15 months. However, additional investigation and testing regarding Phase II discharge to the Little Spokane River were required by Ecology, and halted design progress for about 7 months subsequent to submittal of the Preliminary Plan. A revised estimated Phase II design schedule that incorporates the time required for these additional activities is shown on Figure 1-9. The actual time required for design is dependent on timely EPA and Ecology review. The estimated submittal dates shown on Figure 1-9 are subject to modification if EPA and Ecology review comments and approvals are not provided within the indicated period.

Two EPA and Ecology design reviews of the Plans and Specifications are provided for in the Project Schedule. However, the design delay that occurred in 1992 makes acceleration of this schedule necessary if remedial action construction is to occur in 1993. Spokane County will request approval of the final design subsequent to EPA and Ecology reviews of the Preliminary Plans and Specifications, contingent upon Spokane County adequately addressing EPA and Ecology comments on that document and this Final Plan.



* As specified in the ROD (EPA 1987)

Regional Location Map

Figure 1-1

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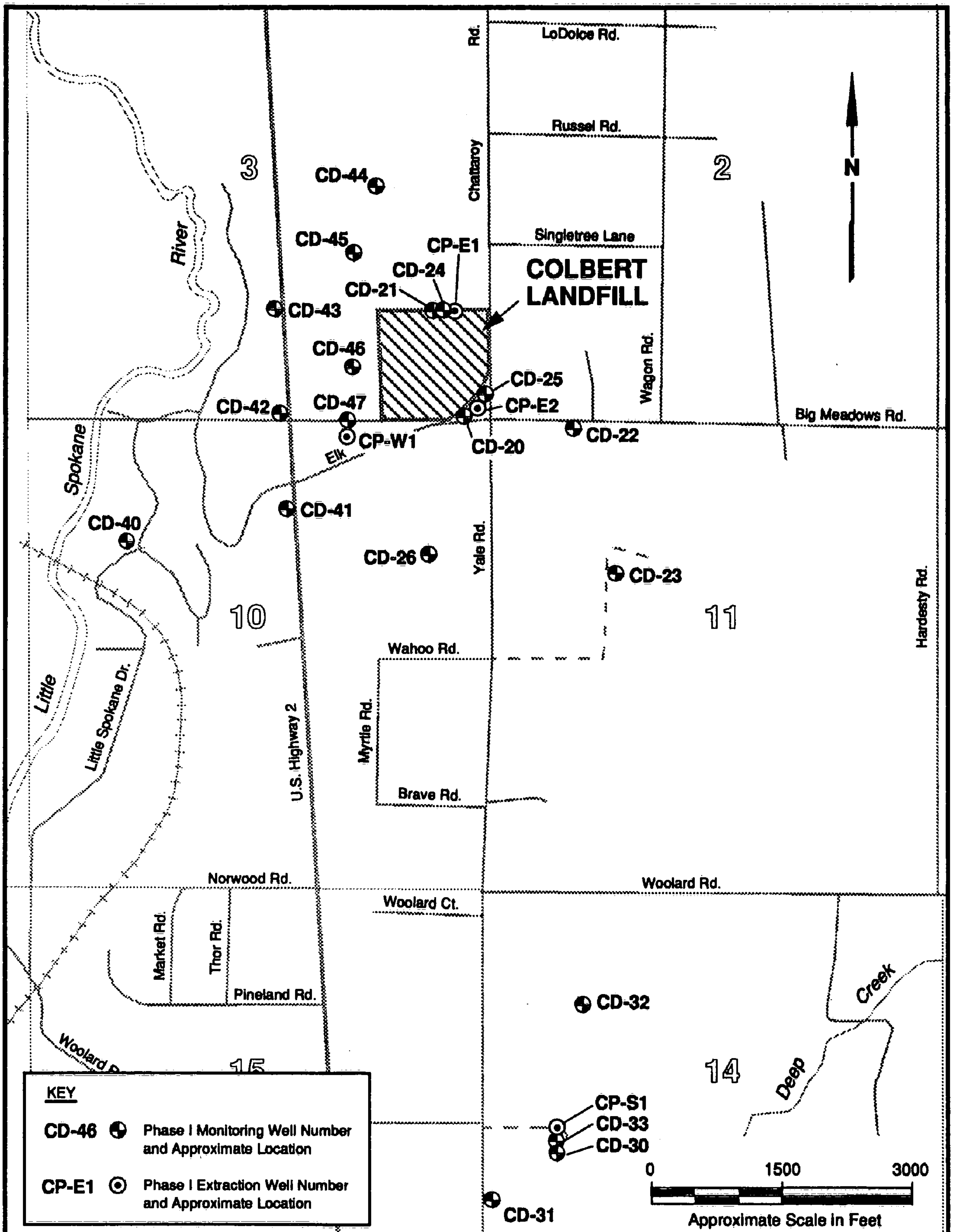
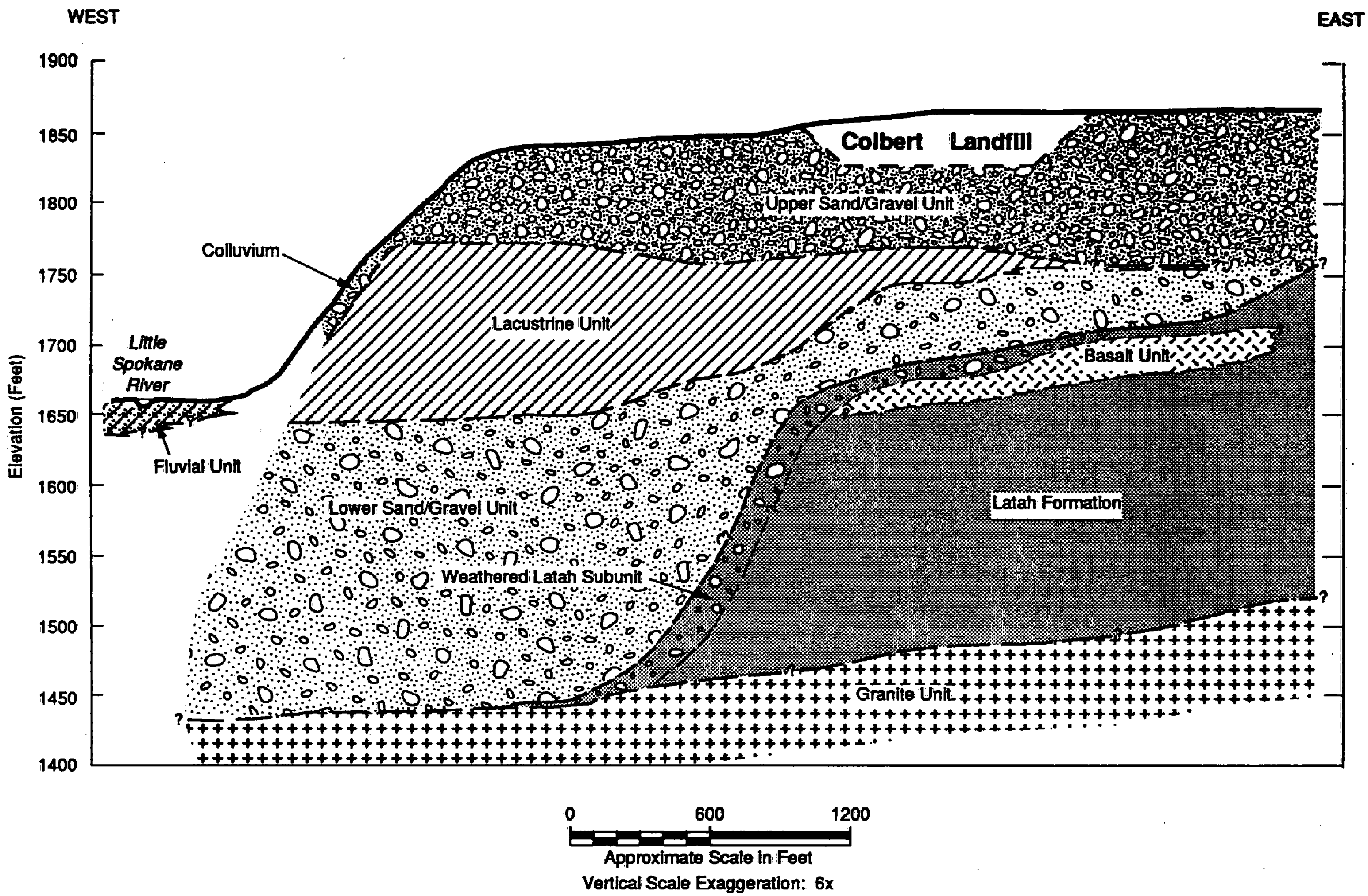


Location of Phase I Monitoring and Extraction Wells

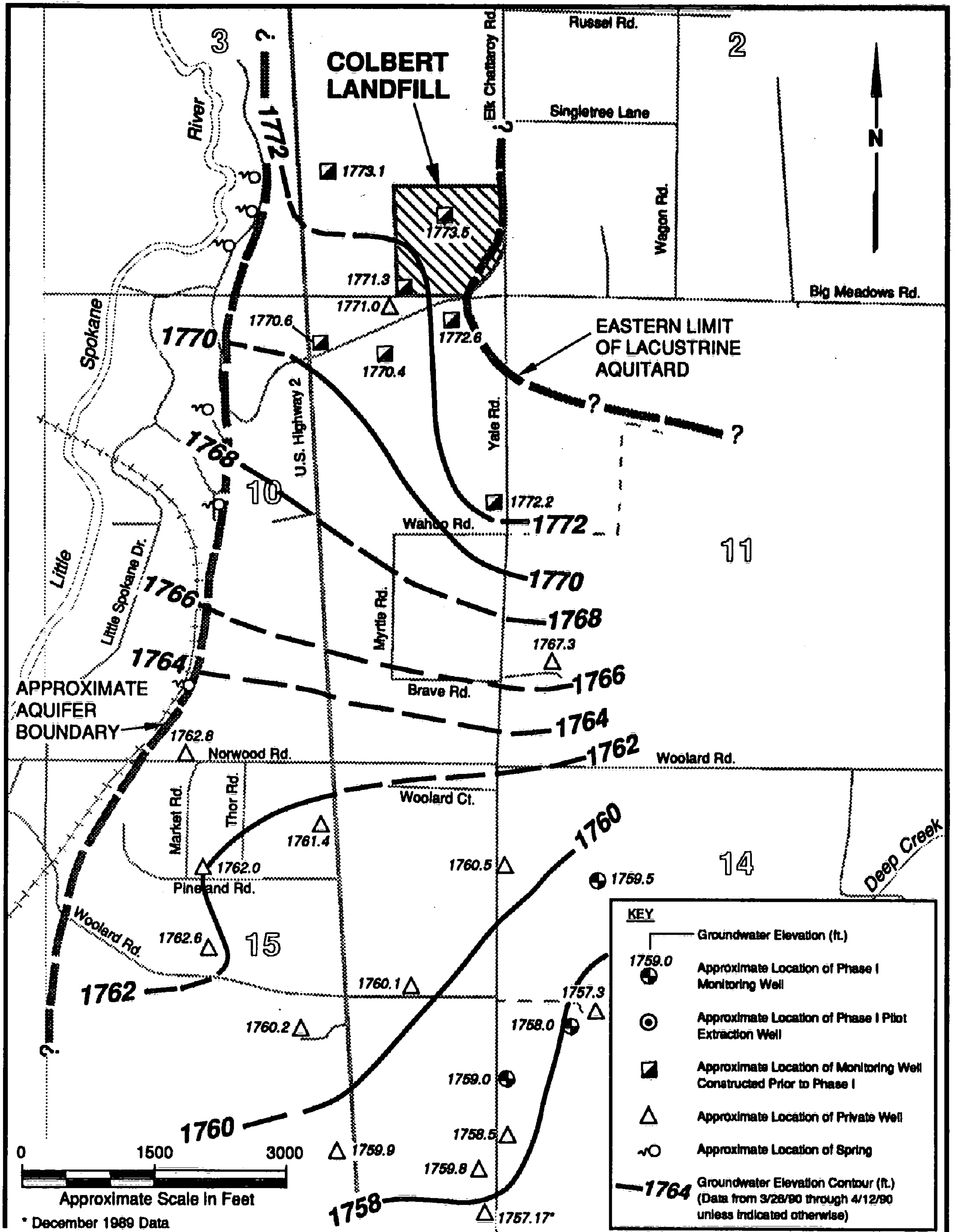
Figure 1-2

124001.73 Spokane Co./Colbert Landfill RD/RA Phase II/Final Treatment & Discharge Plan 2/93



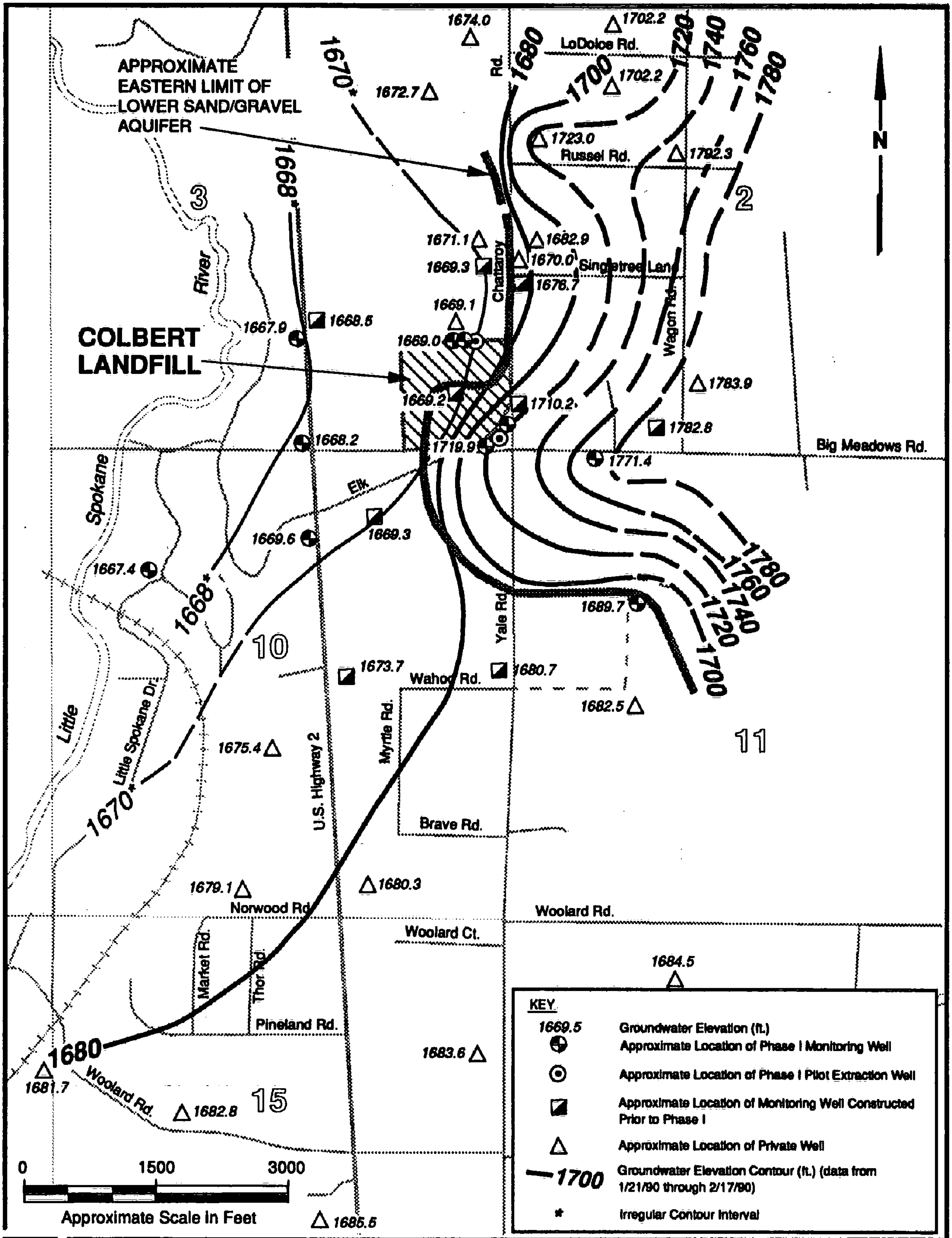
Generalized East-West Geologic Profile

Figure 1-3



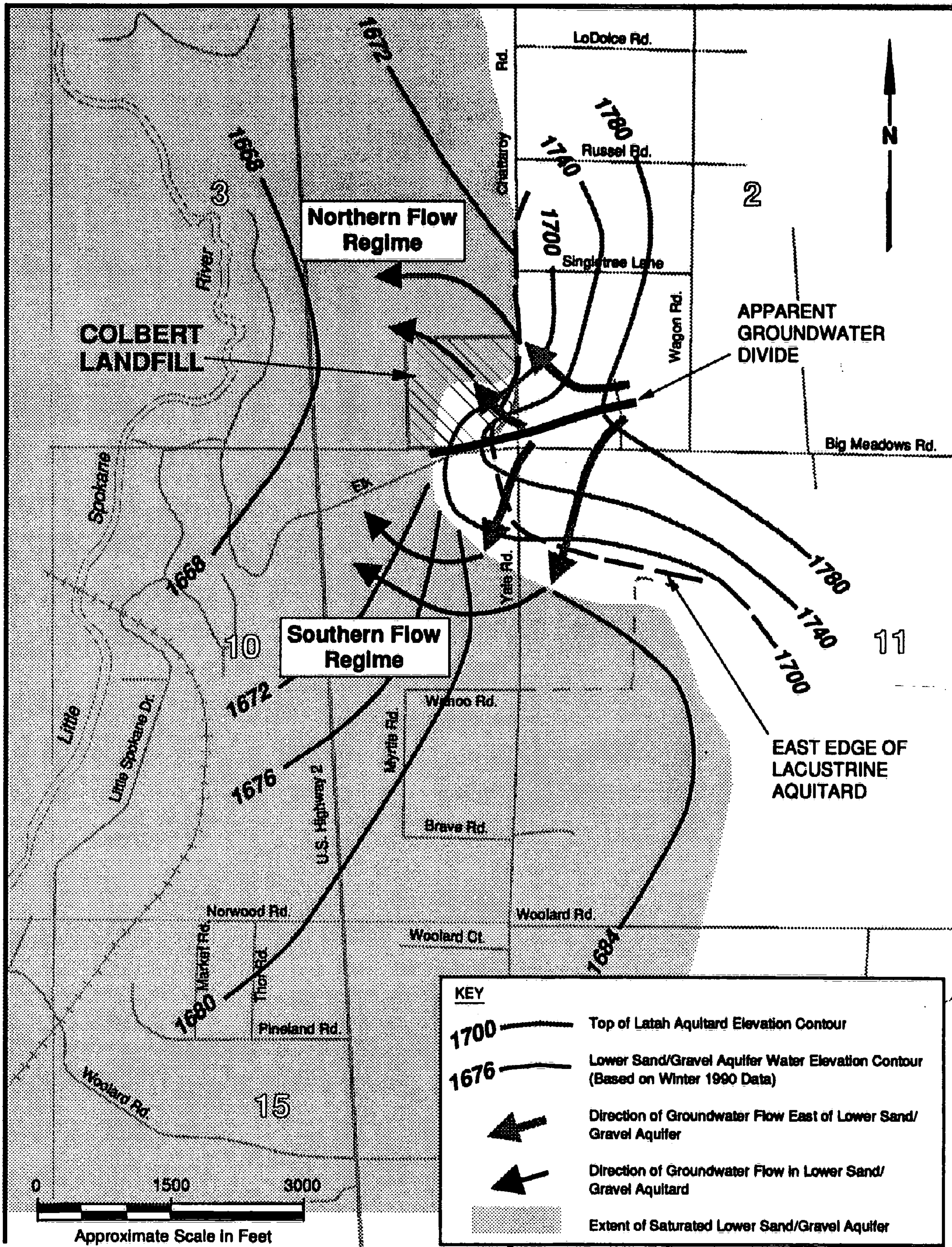
Upper Sand/Gravel Aquifer
Groundwater Elevation Contours

Figure 1-4



Lower Aquifers
Groundwater Elevation Contours

Figure 1-5



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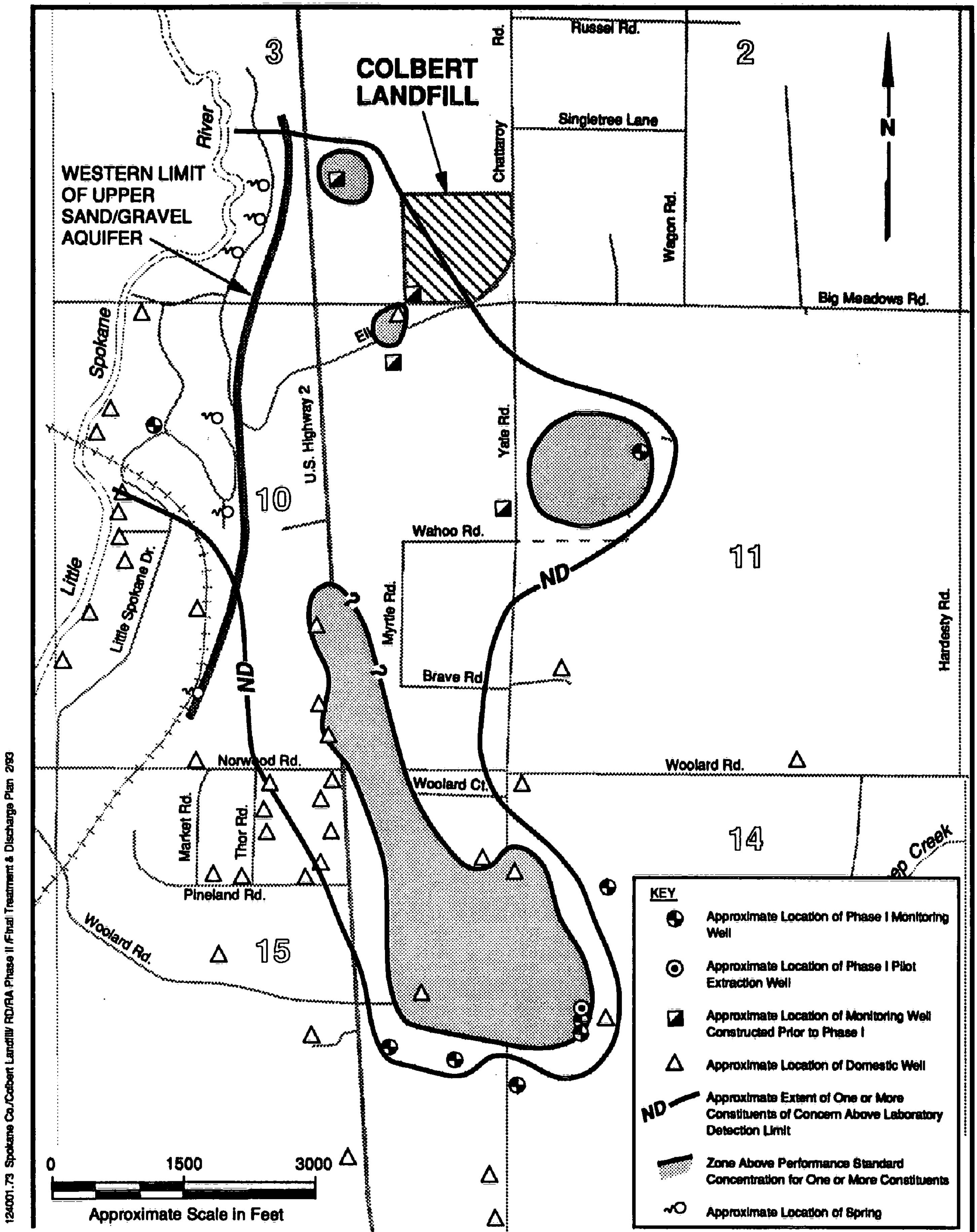
Conceptual Model
Lower Aquifers Groundwater Flow

Figure 1-6



Upper Aquifers
Approximate Extent of Constituents of Concern

Figure 1-7

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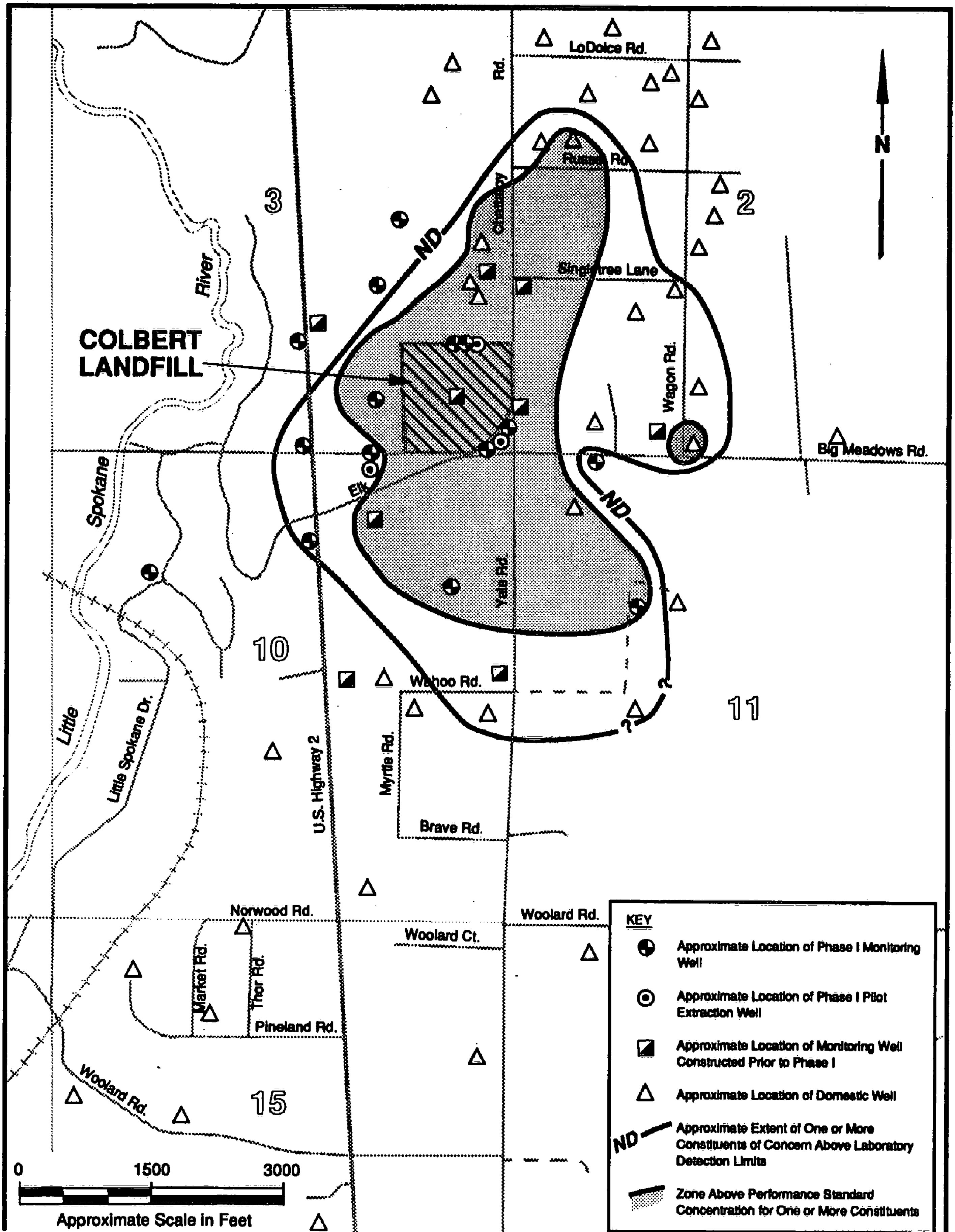

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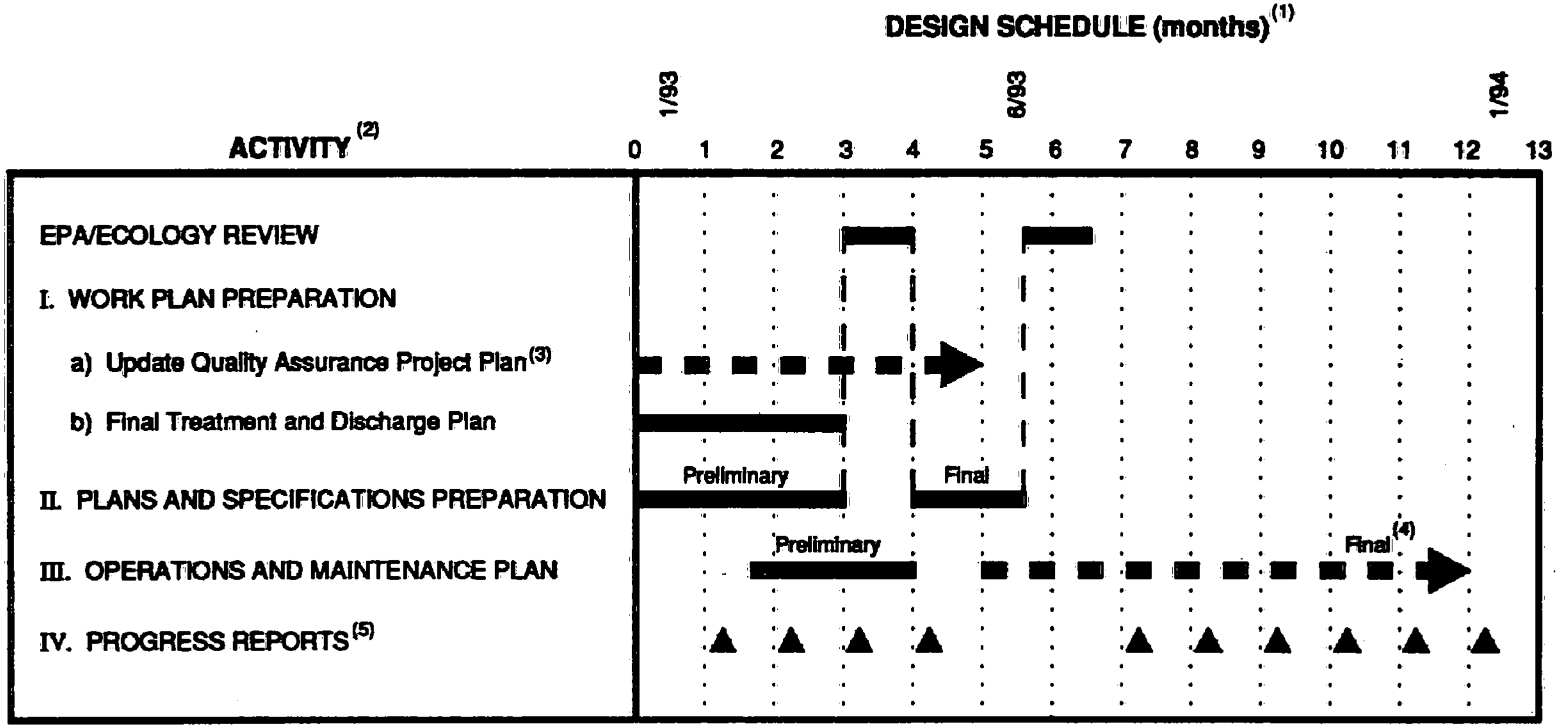
Lower Aquifers
Approximate Extent of Constituents of Concern

Figure 1-8

LANDAU ASSOCIATES, INC.



Notes: 1. 1/93 ← Estimated date. Actual dates for submittals may be modified if EPA/Ecology reviews are not completed within the allocated period.

1 2 ← Time in months since EPA/Ecology approval to proceed with Phase II design.

2. Schedule only addresses uncompleted design activities.
3. QAPjP to be updated following resolution of NPDES issues.
4. Final O&M Plan to be submitted at the completion of Phase II construction.
5. Progress reports to be submitted monthly during periods of construction, and quarterly at other times.

Phase II Design
Estimated Schedule

Figure 1-9

TABLE 1-1[a]

PROJECT PERFORMANCE CRITERIA[b]
COLBERT LANDFILL RD/RA

Constituent of Concern	Performance Standards	Evaluation Criteria
1,1,1-Trichloroethane (TCA)	200	200
1,1-Dichloroethylene (DCE)	7	7
1,1-Dichloroethane (DCA)	4050	4050
Trichloroethylene (TCE)	5	5
Tetrachloroethylene (PCE)	0.7	7
Methylene Chloride (MC)	2.5	25

(a) From Consent Decree Scope of Work (U.S. District Court 1988).

(b) All concentrations in parts per billion (ppb).

2.0 TREATMENT SYSTEM DESIGN

This section presents the final design criteria and preliminary design for the Phase II treatment system. Treatment system design elements presented in this Final Plan include:

- Final design criteria for the Phase II air stripping treatment system, based on the planned extraction well system
- Final design criteria for the scale control process to be implemented for the Phase II treatment system
- The process flow diagram.

It is intended that this Final Plan be reviewed in conjunction with the Phase II Preliminary Plans and Specifications (90 percent design) submittal for a more comprehensive understanding of the Project design.

2.1 BASES OF DESIGN

2.1.1 Consent Decree Requirements for Treated Groundwater

Section V of the SOW specifies the basis for design of the Phase II treatment system. The treatment system must be designed to achieve the Performance Standards and the treatment system must be modified if the Evaluation Criteria are not met during operation. These criteria are presented in Section 1.1 of this Final Plan, and are reproduced in Table 2-1. These criteria establish the level of treatment required for the extracted groundwater.

2.1.2 Phase I Treatability Study Results

Groundwater treatability studies were conducted during Phase I to provide data for design of the Phase II treatment facility. The Phase I treatability study results are provided in Section 4.4 of the Phase I Engineering Report (Landau Associates 1991), and include the following conclusions:

- Air stripping is capable of treating extracted groundwater to the Performance Standards
- Methylene chloride is the Constituent of Concern controlling stripping tower design
- The mass transfer coefficient for Phase II design must be modified to calibrate model-predicted stripping tower performance to observed performance during Phase I treatability studies

- Chemical scale control will be needed for the Phase II treatment facility.

These conclusions form the bases for the scope of treatment system design and the design approach.

2.1.3 Influent Design Flows

Estimated influent design flows are developed in the Final Extraction Well Plan (Landau Associates 1992b), for design of the Phase II interception and extraction systems. Minimum and maximum design flows rates are 600 and 1,600 gallons per minute (gpm), respectively, and the anticipated flow rate is 1,000 gpm. The Final Extraction Well Plan (Landau Associates 1992b) should be reviewed for additional discussion of interception/extraction system design.

The Final Extraction Well Plan, coupled with information developed during the ongoing Phase II well construction program, provides the basis for the currently planned interception extraction system. The currently planned South and West Interception Systems and East Extraction System are shown on Figure 2-1. The anticipated and maximum design flow rates for the interception/extraction systems are presented in Table 2-2.

2.1.4 Influent Design Concentrations

Two influent design concentrations are used as the treatment system design bases: 1) anticipated concentration, and 2) maximum design concentration. The anticipated concentrations represent the peak concentrations predicted for Phase II operation. The maximum design concentrations represent the probable maximum influent concentration that could be encountered during operation of the Phase II treatment system, although these concentrations are not anticipated to occur during Phase II operation.

The anticipated influent concentrations were developed based on the groundwater flow and solute transport modeling described in the Final Extraction Well Plan (Landau Associates 1992b), in conjunction with recently developed information regarding the currently planned interception/extraction well system. Anticipated concentrations were developed only for MC and TCA. MC is the Constituent of Concern controlling stripping tower design, and TCA is the Constituent of Concern present at the highest concentration. The anticipated design concentrations for MC and TCA in each well, and the anticipated concentrations influent to the treatment system, are presented in Table 2-3. Anticipated concentrations are expected to occur early in Phase II operation, and decrease with time.

The maximum design concentrations influent to the treatment system are presented in Table 2-4. The maximum design concentrations for MC and TCA are equal to the highest concentration modeled for an influent conveyance line discharging to the treatment system (for pipeline conveying water from Wells CP-W2, CP-W3, CP-E1, and CP-E3), as presented in the Final Extraction Well Plan (Landau Associates 1992b). Maximum design concentrations for DCE, DCA, TCE, and PCE are the highest concentrations observed in groundwater samples collected during Phase I. These influent concentrations represent conservative estimates for Phase II design. The Final Extraction Well Plan (Landau Associates 1992b) should be reviewed for additional discussion of influent design concentrations.

2.2 SCALE CONTROL PROCESS DESIGN

2.2.1 Description of Scale Formation

Scale control is identified as a necessary component of the Phase II treatment system based on observations during Phase I treatability studies and the results of the bench tests. Scale accumulation on the stripping tower packing can impede air and water flow through the stripping tower, and reduce the available surface area for mass transfer from the water to the air. In addition, scale formation can reduce the flow capacity of the effluent piping, potentially rendering it nonfunctional. The scale formation potential identified from bench test results (described in Section 2.2.3) indicate that an adverse impact on the Phase II treatment system operation from scale formation is probable if scale control is not implemented.

The scale formed during the Phase I treatability studies consisted primarily of precipitated calcium carbonate. Calcium carbonate ($CaCO_3$) scale formation is caused by two phenomena: 1) stripping of carbon dioxide (CO_2) from the water to the air, causing the dissolved calcium bicarbonate [$Ca(HCO_3)_2$] in the groundwater to convert to calcium carbonate per Equation 1; and 2) formation of hydroxyl ions, with a resultant rise in pH due to carbon dioxide stripping per Equation 2, which react with calcium bicarbonate ($CaHCO_3^-$) ions to form calcium carbonate and water, per Equation 3.

(1) $Ca(HCO_3)2 \longrightarrow CaCO_3 \text{ (solid)} + CO_2 + H_2O$

(2) $HCO_3^- \longrightarrow CO_2 + OH^-$

(3) $CaHCO_3^- + OH^- \longrightarrow CaCO_3 \text{ (solid)} + H_2O$

2.2.2 Evaluation of Scale Control Process Options

Options for scale control evaluated in the Preliminary Plan (Landau Associates 1992a) included: 1) addition of a sequestering agent, which reacts with the calcium bicarbonate to prevent calcium carbonate precipitation; 2) control of the pH of the groundwater to maintain the calcium in the soluble calcium bicarbonate form; 3) batch cleaning of tower internals using dilute acid to remove precipitated scale; or 4) removal of the calcium from the groundwater before entering the air stripping tower.

Subsequent to this analysis, a bench testing program was conducted which identified the scale formation potential for the predicted Phase II groundwater influent to the treatment system, and demonstrated that both phosphate and nonphosphate sequestering should be effective in controlling scale deposition in the air stripping tower. These results are the basis for selection of sequestering agent addition as the primary scale control process.

Removal of calcium from groundwater prior to air stripping was eliminated from further consideration in the Preliminary Plan because the available processes generate large volumes of waste and have high capital and operating costs. Control of pH was eliminated from further consideration due to the high operational costs, as well as the results of the bench tests performed subsequent to completion of the Preliminary Plan (described in Section 2.2.3), which indicate that sequestering agent addition is effective in controlling scale formation.

2.2.3 Scale Control Bench Tests

Laboratory bench tests were performed to evaluate the effectiveness of sequestering agent addition to the groundwater influent stream to inhibit calcium carbonate scale formation. The bench tests were performed on groundwater samples collected from representative monitoring wells, and composited to reflect anticipated Phase II influent water quality characteristics.

Groundwater samples were collected from four Phase I monitoring wells (CD-21C1, CD-46C2, CD-47C2, and CD-30A) in August 1992. Composite samples were prepared from these samples by combining aliquots of each well sample. Each aliquot was volume-proportional to the estimated relative contribution of groundwater from the well vicinity to the total estimated Phase II design flow.

The Calcium Carbonate Stability Test (American Water Works Association, Inc. 1971), commonly referred to as the "marble test," was used to estimate the scale potential for Phase II groundwater, and evaluate the effectiveness of sequestering agent addition. The results of these analyses indicate that Phase II groundwater has a scale potential of about 20 mg/L of calcium carbonate, which is equivalent to about 240 lb/day at a 1,000 gpm flow rate. Although this scale accumulation rate is significant, it is only about 15 percent of the scale accumulation rate observed for the well with the highest scale potential (CD-E1) used during Phase I treatability studies.

Both phosphate (Betz 419) and nonphosphate (NALCO 8357) sequestering agents were evaluated for effectiveness in inhibiting scale formation. Test results indicate that both phosphate and nonphosphate sequestering agents are effective, although tests for the nonphosphate sequestering agent are inconsistent at sequestering agent addition rates in the 12-20 ppm range. Based on the bench test results, a sequestering agent addition rate of 5-10 ppm should be adequate for the phosphate-based sequestering agent, and an addition rate of 10-15 ppm should be adequate for the nonphosphate sequestering agent.

The bench test results indicate that the phosphate sequestering agent, and possibly the nonphosphate sequestering agent, should be 100 percent effective in inhibiting scale accumulation. However, the analytical method for hardness is only accurate to about 10 mg/L at the hardness concentrations analyzed. As a result, relatively low concentrations of scale may form that are not detectable using standard analytical methods. For the purpose of evaluating the need for scale control measures other than sequestering agent addition, it is assumed that sequestering agent scale control will be 90 percent effective, which results in a scale accumulation rate of 2 mg/L (24 lb/day at a 1,000 gpm flow rate). A detailed description of bench test procedures and results is presented in Appendix A.

2.2.4 Description of Selected Scale Control Processes

2.2.4.1 Sequestering Agent Addition

Scale formation can be controlled by addition of a sequestering agent to the groundwater, which reacts with the calcium bicarbonate to form a compound that resists precipitation. Once the calcium reacts with the sequestering agent, it resists combination with the carbonate ions to form insoluble calcium carbonate. The addition of a sequestering agent may not completely eliminate the formation of calcium carbonate scale, but can significantly reduce the rate of scale deposition through reduction of the calcium available to form scale.

Commercially available sequestering agents include both long chain polyphosphates and nonphosphate-based polymers. The polyphosphate sequestering agents have been in use for scale control for over 50 years. The nonphosphate sequestering agents are relatively new and application to air stripping has not been documented.

Based on the results of the bench tests (see Section 2.2.3), Phase II operation will be initiated using a nonphosphate sequestering agent. However, because of the lack of performance data, and the less consistent performance achieved by the nonphosphate sequestering agent during bench testing, a polyphosphate sequestering agent may be required if the nonphosphate sequestering agent is ineffective. As discussed in Section 5.0, state surface water quality standards for phosphorus concentrations in the Spokane River may impact Project phosphorus discharges on a seasonal basis, possibly limiting the use of a polyphosphate.

Addition of the sequestering agent is accomplished by metering the liquid into the air stripping tower influent stream. Reagent addition is based on achieving a target dosage in the groundwater influent to the air stripping tower. Based on bench scale results, the anticipated dosages are up to 15 ppm for the nonphosphate sequestering agent and up to 10 ppm for the polyphosphate sequestering agent.

2.2.4.2 Batch Cleaning of Tower Internals

Batch cleaning of the tower internals is intended to periodically remove accumulated scale by dissolving it into a dilute acid solution, typically hydrochloric acid (HCl). The extraction and treatment systems must be shut down during the batch cleaning, which will take from one to two days. The frequency of batch cleaning will depend on the hardness of the influent, the effectiveness of the sequestering agent, and the amount of scale allowed to accumulate prior to batch cleaning.

Determination of when batch cleaning is necessary, as well as when adequate cleaning has been achieved, will be based on visual observation of the tower internals through an access portal, and on inspection and measurement of scale accumulation on test coupons installed in the tower. Uncertainty exists in estimation of the cleaning frequency due to the uncertainty associated with the performance of the sequestering agent. However, a batch cleaning frequency of once per year was selected as the design goal.

Typical batch cleaning uses dilute HCl (10 percent by weight solution) recirculated through the tower for 8 to 24 hours. A silicone based defoaming polymer is also added at a dosage of 20 to 30 ppm to suppress foam generated by CO_2 liberation. The stripping tower clear well is initially charged with water, and a 35 percent HCl solution will be added to achieve the required concentration. Based on 8,800 lb of scale accumulation annually, it is estimated that 1,900 gallons of the 35 percent HCl, or 7,500 gallons of dilute acid, will be required for each cleaning (see calculation 6 through 9 in Appendix B). The proposed 5,000 gal capacity clear well will be filled and emptied two or more times during each batch cleaning.

After the batch cleaning is complete, the spent solution will exhibit low to neutral pH and contain dissolved calcium removed from the tower and the defoaming polymer. If a dedicated acid batch cleaning system is constructed, this solution will be stored onsite in a 10,000-gal tank prior to offsite disposal, or onsite pretreatment and discharge to the effluent piping. If acid batch cleaning frequency does not justify a dedicated system, the spent solution will be removed from the facility for offsite disposal immediately following batch cleaning. Acid usage calculations are presented in Appendix B, equation 7 through 9.

Periodic batch cleaning will be conducted, as necessary, based on observed scale accumulation. Batch cleaning frequency is uncertain. As a result, batch cleaning will initially be performed using contracted services for transportation, storage, and disposal of the spent/batch cleaning solution. A spent batch cleaning solution storage tank and discharge system will be constructed if warranted by the required frequency of batch cleaning.

2.3 TREATMENT SYSTEM PROCESS DESIGN

This section describes the final process design for the Phase II treatment facility. Final treatment system process design includes selection of final design criteria for the stripping tower and the scale control processes to be implemented. The following design elements are included in this section:

- Design criteria for the Phase II air stripping tower
- Process design for the scale control chemical feed and control systems
- Treatment system process flow schematic

The Air Stripping System Procurement Specification, which was included and received regulatory review as part of the Preliminary Plan (Landau Associates 1992a) was removed from this Final Plan and will be submitted under separate cover as part of the Final Phase II Plans and Specifications.

2.3.1 Air Stripping Tower Final Design

Although the Phase II air stripping tower will be procured using a performance-based specification, final design criteria have been established to define a minimum standard that must be achieved by manufacturers, and to provide a basis for evaluating the adequacy of the manufacturer-proposed system configuration. A minimum design standard is particularly important when mass transfer for the constituent controlling design (MC) typically cannot be accurately predicted using the (unadjusted) design equations commonly used for stripping tower design, as is the case for this Project.

The Phase I treatability studies identified MC as the Constituent of Concern controlling Phase II treatment system design (Landau Associates 1991), and consequently the design analysis is focused on this constituent. The 3.5-inch diameter Jaeger Tripacks were selected for design modeling, because this packing is less prone to fouling by scale than the smaller (2-inch diameter) packing tested during Phase I.

The initial task in developing the preliminary stripping tower design is calibration of the computer simulation model, based on the results of the Phase I treatability studies. The computer model used for this analysis is similar to that presented in the Phase I Engineering Report (Landau Associates 1991), with the calculations reorganized to allow analysis of required tower configuration to achieve effluent performance standards. The model was calibrated by modifying the estimated mass transfer rate constant through the use of an adjustment factor developed from Phase I treatability study data. Table 2-5 presents the adjustment factors for the Constituents of Concern used for treatment system design. Additional discussion of adjustment factor development and the design model are provided in Appendix C.

Initial design for the Phase II air stripping system is based on achievement of effluent Performance Standards under various influent concentrations and flow conditions that represent anticipated, minimum, and maximum design operational conditions. Maximum design operational conditions include high flow and high concentration scenarios. Anticipated, minimum, and maximum design operational conditions are based on Phase II Interception/ Extraction System design (Landau Associates 1992b), as presented in Sections 2.1.3 and 2.1.4 of this Final Plan, and are summarized in Table 2-6.

The design analysis was conducted by varying the tower diameter and air-to-water ratio over a reasonable operating range, and calculating the packing height required to achieve the MC Performance Standard. Several combinations of the design variables were found to achieve required removals within a preliminary target packing height of 50 ft. Consequently, selection of a tower configuration for preliminary Phase II design is primarily an economic decision based on a cost-effective balance of capital and operational costs.

Packing volume can be used as a relative measure of the capital cost of an air stripping tower. The larger diameter the tower, the greater the tower surface area and packing volume, and thus the greater the capital cost. The actual capital cost impact from the increase in packing volume will be quantified during procurement of the air stripping tower.

Energy requirements (and thus costs) can be used as a relative measure of operational costs. The energy requirements were estimated based on the lift required to pump the water to the top of the packing and the air blower horsepower requirements for the tower conditions modeled. This energy calculation does not represent the total system energy requirements, but provides a reasonable approximation of the relative energy requirements for different tower configurations. Energy requirements will be one of the selection criteria used for procurement of the Phase II air stripping tower.

Design analyses were performed for 8-ft, 10-ft, and 12-ft diameter towers to evaluate packing height, packing volume, and energy requirements to achieve the MC effluent Performance Standards. Air-to-water ratios were varied between 60 and 120 (volume:volume). Results of these analyses are summarized in Table 2-7, and computer model input and output data sheets for selected runs are provided in Appendix C.

As shown in Table 2-7, both 10- and 12-ft diameter towers are capable of achieving MC effluent Performance Standards within a target packing height of 50 ft, and maintaining a relatively energy-efficient operation for anticipated and maximum hydraulic loadings and influent concentrations. The 12-ft diameter tower requires significant additional packing volume to achieve minimal energy savings compared to the 10-ft diameter tower. An 8-ft diameter tower exhibits acceptable performance for anticipated conditions and maximum (high concentration) conditions, but requires significantly greater energy than the 10-ft diameter tower to effectively treat the maximum (high flow) condition. Based on the modeling results summarized in Table 2-7, the final design criteria for the Phase II air stripping tower will be performance equivalent to a 10-ft diameter tower with a 50-ft packed height of 3.5-inch diameter Jaeger Tripacks, utilizing a volumetric air to water ratio of 80 to 120 for flows up to 1,600 gpm. It is important to recognize that the successful bidder does not have to directly meet these dimensional criteria, but must demonstrate that the proposed system will perform in an equivalent manner. The final design criteria are summarized in Table 2-8.

2.3.2 Air Stripping Tower Procurement Specification

The air stripping tower will be procured utilizing a performance-based specification based on maximum design influent quality and required effluent quality. The specification allows for alternative packing types, tower dimensions, and air-to-water ratios. The minimum equivalent performance of the stripping system will be based on the final design criteria described in Section 2.3.1, and summarized in Table 2-8. Estimates of stripping tower energy consumption will be required from the suppliers, and will be used as selection criteria in conjunction with capital cost.

2.3.3 Scale Control Final Process Design

As described in Section 2.2.4, the scale control process for the Phase II treatment facility will include a sequestering agent feed system and a batch cleaning system for removing accumulated scale from tower internals.

2.3.3.1 Sequestering Agent Feed System

Sequestering reagent will be injected continuously into the air stripping system influent pipeline. The volume of sequestering agent will be adjusted during system start-up to optimize performance and will likely range up to 10 and 15 ppm for phosphate and nonphosphate sequestering agents, respectively. Daily usage of the sequestering agent, based on a 1,600 gpm influent flow rate and sequestering agent addition rate of 10 ppm will be approximately 20 gallons per day, or 200 lb/day (sequestering agent unit weight of approximately 10 lb/gallon). The sequestering agent feed system will be sized for this maximum flow rate. A 1,200-gallon sequestering agent feed tank will be constructed. This tank will have an operating capacity of approximately 2 months at the peak usage rate. The sequestering agent feed system can be used for polyphosphate or nonphosphate sequestering agents.

2.3.3.2 Batch Cleaning

The target frequency of batch cleaning of the air stripping tower is once per year. A polypropylene scale coupon will be installed in an access nozzle in the stripping tower, and will be visually inspected and measured to determine scale build-up on a planned maintenance schedule (inspection schedule to be provided in the operations and maintenance plan). Scale measurements of about 1 mm will initiate batch cleaning of the tower. Tower air pressure differential will be measured and increased pressure differential will also be used as an indicator for batch cleaning.

When batch cleaning is undertaken, the extraction and treatment systems will be shut down for a period of approximately one to two days. Batch cleaning will involve recirculation of a dilute solution of HCl (10 percent by weight) through the air stripping tower. Foaming will likely occur due to the formation of carbon dioxide from dissolution of the scale. This may necessitate addition of a low-dosage defoaming polymer during the cleaning.

The amount of acid required for annual batch cleaning is estimated based on a sequestering agent scale control efficiency of 90 percent and a 1,000 gpm flow rate, with all scale formation presumed to be in the tower. The stoichiometric relationship of $CaCO_3$ scale dissolution by HCl indicates that 0.7 lb of HCl is required to dissolve 1 lb of $CaCO_3$. This analysis indicates that approximately 1,800 gallons of 35 percent HCl would be required for each annual batch cleaning. The calculations for estimated scale accumulation (and acid requirements) are summarized in Appendix B, equations 6 through 9.

The 1,800 gallons of 35 percent HCl requires dilution to a total volume of about 7,000 gallons (by addition of water) to achieve the target 10 percent concentration. The use of dilute acid is necessary to minimize degradation of tower internals. Consequently, the acid wash storage tank will be sized for this minimum volume. The defoaming polymer is added at a dosage of up to 30 ppm, which would require approximately 2 lb (1 quart) of polymer solution.

2.3.4 Air Emissions Abatement

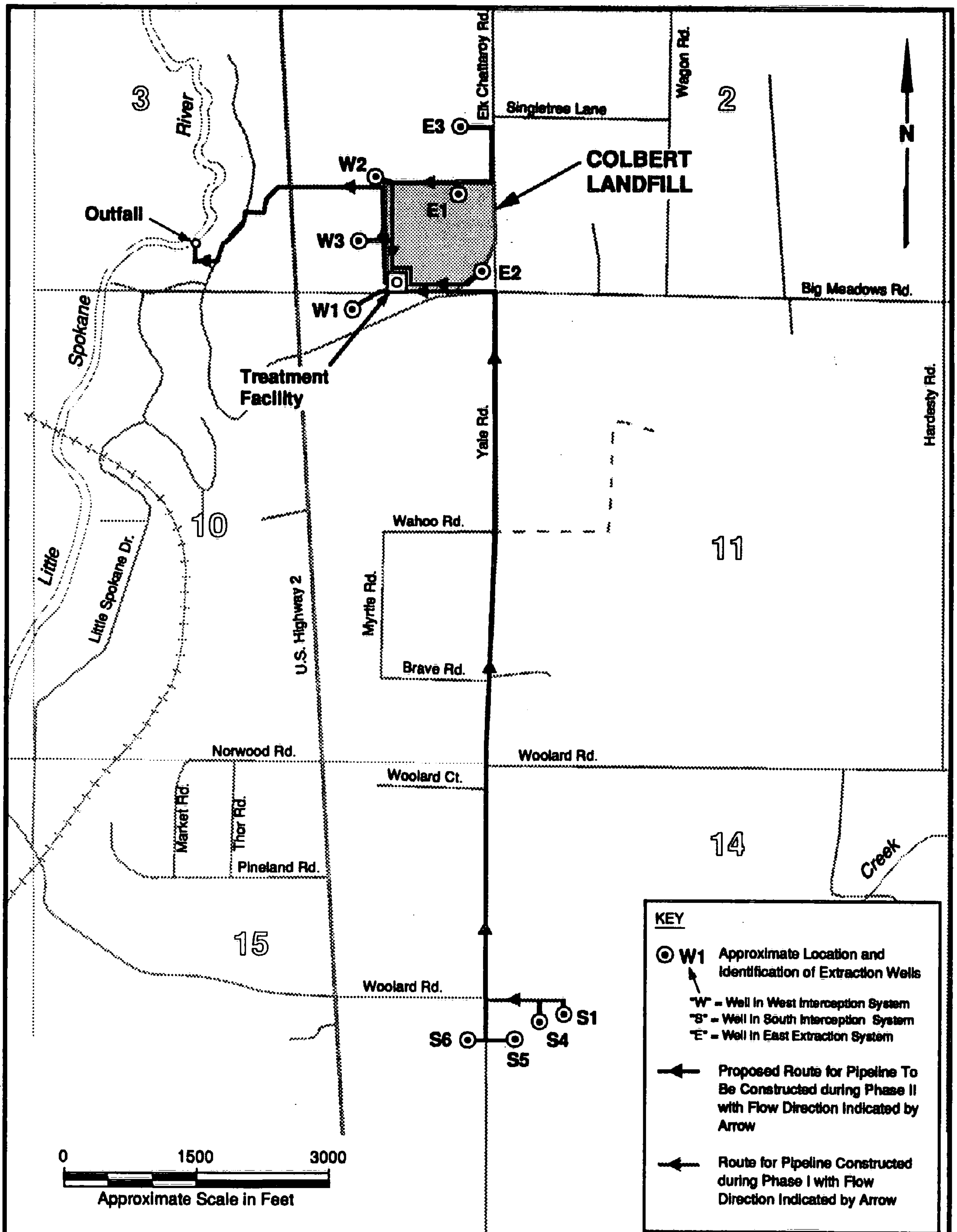
Section V.D. of the SOW specifies that the need for air stripping tower air emissions abatement (offgas treatment) during Phase II remedial action will be evaluated based on life time cancer risk (for carcinogenic compounds) and hazard indices (for noncarcinogenic compounds). Air emissions treatment will not be required if increased cancer risk and hazard indices due to stripping tower air emissions are below 10^{-6} and 1, respectively. Air quality modeling and health risk assessment were performed during Phase I, and are described in Section 4.5 of the Phase I Engineering Report (Landau Associates 1991). The results of these analyses indicate a hazard index of 5.2×10^{-5} and a total excess cancer risk of 2.1×10^{-7} at the location of highest potential exposure. These values are well below their respective criteria (for offgas treatment).

Source parameters (mass flux, stack height, exit velocity) have not changed since the Phase I evaluation. Thus, offgas treatment is not planned for the Phase II remedial action. A final assessment of the need for offgas treatment prior to Phase II construction will be performed after the stripping tower vendor is selected, and the treatment system design is finalized.

Phase II air emissions will be monitored based on the change in concentration of influent and effluent groundwater. The change in groundwater concentration, combined with hydraulic and air flow measurements, provides a more accurate method of determining air emissions than does traditional stack emissions testing. Mass emissions (in lb/day and total lb) will be calculated throughout Phase II operation. If the total mass or mass flux approaches target values that indicate unacceptable health risk, the need for offgas treatment will be reassessed.

2.3.5 Process Flow Schematic

Figure 2-2 presents the process flow schematic for the Phase II treatment system. The groundwater originating from the extraction well system is combined to form a single influent stream into the air stripping tower. A bypass line is provided for direct discharge (without treatment) of influent that meet the direct discharge requirements specified in Section V of the SOW. The scale control unit processes, shown on Figure 2-2, include the sequestering agent addition system and the batch cleaning system.



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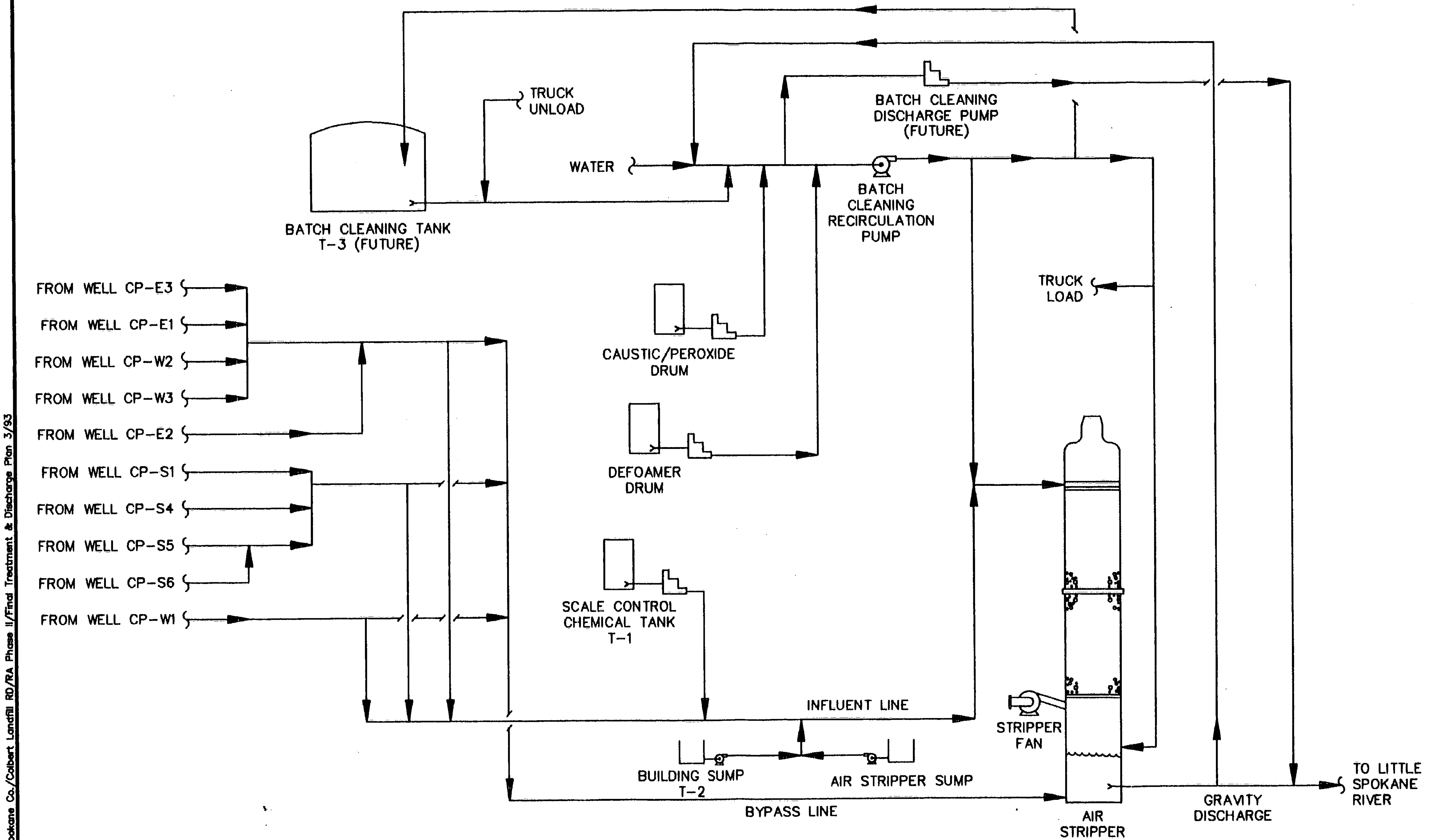
Planned Phase II Extraction Well Schematic

Figure 2-1



Process Flow Schematic
Colbert Landfill Treatment and Discharge System

Figure 2-2

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TABLE 2-1[a]

PROJECT PERFORMANCE CRITERIA[b]

Constituent of Concern	Performance Standards	Evaluation Criteria
1,1,1-Trichloroethane (TCA)	200	200
1,1-Dichloroethylene (DCE)	7	7
1,1-Dichloroethane (DCA)	4050	4050
Trichloroethylene (TCE)	5	5
Tetrachloroethylene (PCE)	0.7	7
Methylene chloride (MC)	2.5	25

(a) From Consent Decree Scope of Work.
(b) All concentrations in parts per billion (ppb).

TABLE 2-2

INFLUENT DESIGN FLOW RATES

Well Number[a]	Anticipated Flow (gallons per minute)	Maximum Design Flow (gallons per minute)
CP-W1	190	250
CP-W2	130	250
CP-W3	240	250
CP-E1	80	180
CP-E2	5	5
CP-E3	65	150
CP-S1	60	120
CP-S4	50	120
CP-S5	60	80
CP-S6	60	80
Total Influent Flow Rate	940	1485
Treatment System Design Criteria	1000	1600

(a) W_ = West Interception System
E_ = East Extraction System
S_ = South Interception System.

TABLE 2-3

ANTICIPATED DESIGN INFLUENT CONCENTRATIONS FOR METHYLENE CHLORIDE (MC) AND 1,1,1-TRICHLOROETHANE (TCA)

Well Number	Anticipated Flow (gallons per minute)	Estimated Peak Concentration (ppb)	
		MC	TCA
CP-W1	190	0	380
CP-W2	130	1300	2500
CP-W3	240	460	2800
CP-E1	80	3400	3800
CP-E2	5	0	960
CP-E3	65	540	1700
CP-S1	60	NA[a]	180
CP-S4	50	NA	350
CP-S5	60	NA	620
CP-S6	60	NA	620
Anticipated Concentration Influent to Treatment Plant[b]		630	1700

(a) NA = not applicable.

(b) Calculated as a flow-weighted concentration from anticipated flow rates and estimated peak concentrations for individual wells.

TABLE 2-4

MAXIMUM DESIGN CONCENTRATIONS[a]

Constituent	Constituent Concentration
Constituents of Concern	
Methylene chloride (MC)[b]	1300
1,1,1-Trichloroethane (TCA)[b]	2500
1,1-Dichloroethylene (DCE)[c]	300
1,1-Dichloroethane (DCA)[c]	180
Trichloroethylene (TCE)[c]	580
Tetrachloroethylene (PCE)[c]	2.9

(a) All concentrations in parts per billion.
(b) Model-estimated value.
(c) Maximum concentration measured during Phase I.

TABLE 2-5

MASS TRANSFER COEFFICIENT DESIGN ADJUSTMENT FACTORS

Constituent	Adjustment Factor[a] (Dimensionless)
Methylene Chloride (MC)	0.30
Trichloroethane (TCA)	0.30
Dichloroethane (DCA)	0.40
Dichloroethene (DCE)	0.40
Trichloroethene (TCE)	0.45
Tetrachloroethene (PCE)	0.50

(a) Adjusted mass transfer coefficient (KLA adj) = $KLA_{theoretical}$ (1-adjustment factor).

TABLE 2-6

ANTICIPATED AND MAXIMUM DESIGN OPERATIONAL CONDITIONS

	Anticipated Operational Conditions	Minimum Design Operational Conditions	Maximum Design Operational Conditions (High Flow)	Maximum Design Operational Conditions (High Concentration)
Methylene Chloride Concentration (ppb)	625	625	625	1300
System Flow Rate (gpm)	1000	600	1600	1000

TABLE 2-7

SUMMARY OF DESIGN ANALYSES[a][b]

Design Run	Tower Diameter (ft)	Air/Water Ratio (Vol/Vol)	Required Packing Height (ft)	Packing Volume (ft^3)	Energy Requirements (HP)
Series 1—Anticipated Flow (1000 gpm), Anticipated MC Concentration (625 ppb)					
1	8	60	63	3200	31
2	8	80	52	2600	34
3	8	100	46	2300	43
4	10	60	60	4700	26
5	10	80	49	3800	23
6	10	100	43	3400	23
7	12	60	58	6500	25
8	12	80	47	5300	21
9	12	100	41	4600	20
Series 2—Anticipated Flow (1,000 gpm), Maximum MC Concentration (1300 ppb)					
10	8	100	52	2600	49
11	8	120	48	2400	64
12	10	80	56	4400	25
13	10	100	49	3800	26
14	12	80	53	6000	24
15	12	100	47	5300	22
Series 3—Maximum Flow (1600 gpm), Anticipated MC Concentration (625 ppb)					
16	8	100	49	2500	236
17	8	120	45	2300	370
18	10	80	52	4100	55
19	10	100	46	3600	74
20	10	120	42	3300	98
21	12	80	50	5600	38
22	12	100	44	4900	40

(a) Minimum successful design run for each tower diameter to achieve MC Performance Standard with a packing height <50 ft is shaded.

(b) Highlighted rows are design runs which achieved required removal in target packing height of 50 ft.

TABLE 2-8

FINAL DESIGN CRITERIA
FOR PHASE II AIR STRIPPING SYSTEM PROCUREMENT

Item	Design Criteria
Packing Type	3.5-inch Diameter Jaeger Tripack[a]
Tower Diameter	10 ft
Packing Height	50 ft
Air-to-Water Ratio (Volume/Volume)	80-120

(a) Alternate packing materials with equivalent performance will be allowed.

3.0 DISCHARGE SYSTEM DESIGN

This section addresses design of the Phase II discharge system, which includes influent and effluent conveyance piping, and the effluent discharge outfall. Discharge system design includes sizing and routing of conveyance piping, and identification of material specifications and construction requirements.

3.1 BASIS OF DESIGN

Section V of the SOW provides the basis for design of the Phase II discharge system, and specifies that treated water will be discharged to the Little Spokane River, Deep Creek, or subsurface infiltration. These options were evaluated during Phase I, and discharge to the Little Spokane River was selected as the preferred alternative (Landau Associates 1991). It was also decided during Phase I that groundwater treatment could be most economically implemented at a central treatment facility, and that the Treatment Facility would be located near the southwest corner of the Landfill. Thus, untreated groundwater will be conveyed to the southwest corner of the Landfill, and treated groundwater will be conveyed from the Treatment Facility to the Little Spokane River.

3.2 PIPELINE ROUTING

Pipelines are generally routed to convey water from the ten extraction wells to the Treatment Facility using the most direct alignment practicable. It is common practice for pipelines to be routed along public right-of-ways or property boundaries to minimize the impact on private property; this approach will be used for the Phase II discharge system.

Pipeline routing for the Project is controlled by the location of the extraction wells, the location of the Treatment Facility, and the location of the discharge into the Little Spokane River. The locations of the extraction wells, Treatment Facility, and pipeline alignments, are shown on Figure 3-1. As indicated on Figure 3-1, some pipeline segments were constructed during Phase I. These Phase I segments are being incorporated into the Phase II discharge system.

3.3 PIPELINE SIZING

All pipelines are designed as force mains (except as subsequently noted for the 12-inch diameter effluent discharge line). Pipelines are sized to convey anticipated maximum design flow rates with a design velocity adequate to provide self cleaning without excessive friction losses. Design velocities do not exceed 6 ft/sec, and are in general between about 2 to 5 ft/sec.

Influent piping to the Treatment Facility includes individual well piping from each extraction well to a primary conveyance line. Each primary conveyance line conveys water for one or more extraction wells to the Treatment Facility, or to a larger conveyance line. Individual well piping is designed to convey discharge equivalent to the well capacity (independent of design flows). Primary conveyance piping is designed to convey the maximum design flow, including capacity for potential system expansion.

Design flow rates, pipeline velocities, and pipeline design diameters for influent piping are provided in Table 3-1. Pipeline segments identified in Table 3-1 are shown on Figure 3-1.

The effluent discharge piping was constructed during Phase I, and consists of 12-inch diameter pipe and outfall structure. The discharge pipeline will flow by gravity, with influent water head of up to 6 ft above grade provided by the air stripper clear well and foundation. The discharge line has a gravity full pipe flow capacity equivalent to the 1,600 gallons per minute maximum design flow rate for the treatment system. As-built drawings of the discharge pipeline were used to determine actual pipeline elevations and gradients.

3.4 MATERIALS OF CONSTRUCTION

All conveyance pipe will conform to ASTM D 2241-84 polyvinylchloride (PVC) pressure rated pipe. Pipelines, will be constructed using Class 160 PVC pipe with a standard dimension ratio (SDR) of 26. All piping (including couplings and fittings) will have "twin seal" styrene-butadiene rubber (SBR) gasket joints. The system will have a minimum pressure rating of 160 psi. Also, pipeline materials will conform to the standards of the National Sanitation Foundation and U.S. Department of Commerce product standards for potable water piping. The piping materials are designed and manufactured with a minimum safety factor of 200 percent.

Calculations were made to estimate operating, water hammer, and total (operating plus water hammer) pipeline pressures. Operating pressure is the pressure resulting from pipeline frictional losses and elevation changes in the system, and is typically the highest (for a relatively flat site) at the well head. Water hammer is a rapid change in pressure resulting from a variation in the flow rate, and can be significant when pipe flow velocities are rapidly changed (such as by opening or closing a valve, or during a power failure). Water hammer can be calculated by the following equation (Merritt 1983):

$$P = \frac{\rho UV}{144}$$

Where:

P	=	pressure in psi
U	=	velocity of the pressure wave along the pipe in ft/s
V	=	velocity of flow in pipe in ft/s
ρ	=	density of water = 1.94 lb-sec^2/ft^4

U is calculated using the following formula:

$$U = \sqrt{\frac{E}{\rho}}\sqrt{\frac{1}{1 + ED/E_p t}}$$

Where:

U	=	velocity of valve along pipe, ft/s
E	=	modulus of elasticity of water 43.2x10^6 lb/ft^2
D	=	diameter in ft
ρ	=	density of water 1.94 lb-sec^2/ft^4
E_p	=	Modulus of elasticity of pipe material lb/ft^2 = 57.6x10^6 lb/ft^2
t	=	Wall thickness in ft: 4 inch PVC = 0.015 ft 6 inch PVC = 0.023 ft 8 inch PVC = 0.030 ft

Because the water hammer pressure is directly proportional to the flow velocity, the potential for creating the highest water hammer pressure is at the location where flow velocities are the greatest. For this Project, the highest pipeline velocities will generally occur near the Treatment Facility, where the highest design flows occur.

Total pressure is the sum of the operating pressure and the water hammer pressure. The maximum total pressure can be conservatively estimated (high) by adding the maximum estimated operating pressure to the maximum estimated water hammer pressure for a given pipeline. Because these maximum pressures will most likely occur at opposite ends of the pipeline (i.e., operating pressure at the well head and water hammer at the Treatment Facility), it is unlikely that the total pressure estimated in this manner will be experienced during operation. Table 3-2 presents estimated maximum operating, water hammer, and total pressures for the three pipelines that enter the treatment facility, using the calculation method described above. Calculations are based on the design flows and pipeline diameters shown in Table 3-1.

As shown in Table 3-2, the maximum total pressure is 135 psi, which is less than the 160 psi rated capacity of the specified pipe. Because the pipe has a factor of safety of 200 percent incorporated into its design and manufacture, and water hammer pressures are a transient occurrence, the Class 160 PVC pipe is considered adequate for water hammer protection. Additionally, slow-close check valves, and variable frequency drives for extraction well pumps, will be used to minimize water hammer occurrence.

During normal operation, the pipeline is expected to perform with nondetectable leakage at pipe joints. To verify pipe competency, each pipeline will be hydrostatically tested at 150 percent of maximum operating pressure per the State of Washington Department of Ecology *Criteria for Sewage Works Design for Sanitary Force Mains* (Ecology 78-5, Chapter 3, page 47). Pressure piping will be hydrostatically tested at 150 psi for one hour during installation; which is at least 50 percent greater than maximum operating pressure. A maximum pipeline length of about 1,500 ft will be used for each test.

During the hydrostatic testing, the pressure will be monitored closely to verify conformance with specified pipe competence at 50 percent greater pressure than normal maximum operating pressure. In conformance with the above standards, the maximum allowable leakage will be calculated using the following formula, modified from the above standard (Chapter 3, page 47):

$$L = \frac{D(P)^{0.5}}{1{,}850}$$

Where:

L = allowable leakage in gallons per hour per joint

D = nominal pipe diameter in inches

P = test pressure in psi.

If any pipeline segment does not comply with test specifications, the noncompliant pipe segments will be identified, repaired, and retested until specified performance is achieved. Isolation valves and test connection points will be provided at intervals not exceeding 1,500 ft (see Figures 3-2 and 3-7). Test connection points will also be provided at the well heads.

The velocity and pressure of water in the force main creates lateral thrust at any vertical or horizontal bend or tee. Thrust forces have been calculated for all vertical and horizontal bends, and thrust restraint blocks have been incorporated into the design. Thrust restraint will be provided by the use of concrete thrust blocks. At points where the pipe changes direction, such as ties, wyes, elbows, caps, valves, and reducers, thrust blocks will be required. The thrust blocks will be poured in place and will have at least the bearing area against undisturbed earth, as shown on Figure 3-3. At certain points, vertical thrust blocks will be installed per Figure 3-4.

All piping will be installed with a minimum cover depth of 4.5 ft to minimize the potential for damage due to freezing and frost damage (heaving). In all cases, the influent force main will installed below all potable water system crossings, and will be encased for 10 horizontal feet minimum from each side of the water line, as shown on Figure 3-5. The average frost depth for the Spokane area is about 2.5 ft.

To assist future location of pipe in the field, metallic locating wire consisting of #6 galvanized wire and a metallic tape with an appropriate marking will be installed in a continuous strand 3 ft above the pipe. The force main piping will be designed to a continuous grade, whenever possible, to minimize high and low points.

The maximum allowable pipe deflection at any joint will be one degree. In locations where high points are unavoidable because of existing ground conditions and at intervals not exceeding 2,500 ft, special control fixtures will be installed to protect the flow characteristics by relieving trapped air and gas. There are two types of special control fixtures anticipated, air relief valves and combination air/vacuum relief valves, appropriately sized. These valves will be housed in suitable manhole structures for easy access (see Figure 3-6). These valves are designed to allow air to enter or exit the pipeline while preventing water from exiting the pipe. Capture air relief valves (CARVs) allow the release of small volumes of air entrained during filling of the pipeline, allow the release of small volumes of air released during operation of the pipeline, and they allow air to enter the pipeline in the event that a vacuum is formed. The air and vacuum relief valve installation details are shown on Figure 3-7.

Pipeline backfill will be required to meet the following material specifications; with special emphasis on the bedding to protect the physical pipe structure.

- Bedding material will be installed from 6 inches below pipe invert to 6 inches above top of pipe. Bedding material shall consist of crushed, processed, or naturally occurring granular material meeting Washington State Department of Transportation (WSDOT) specification 9-03.12(3) for gravel backfill for pipe bedding.

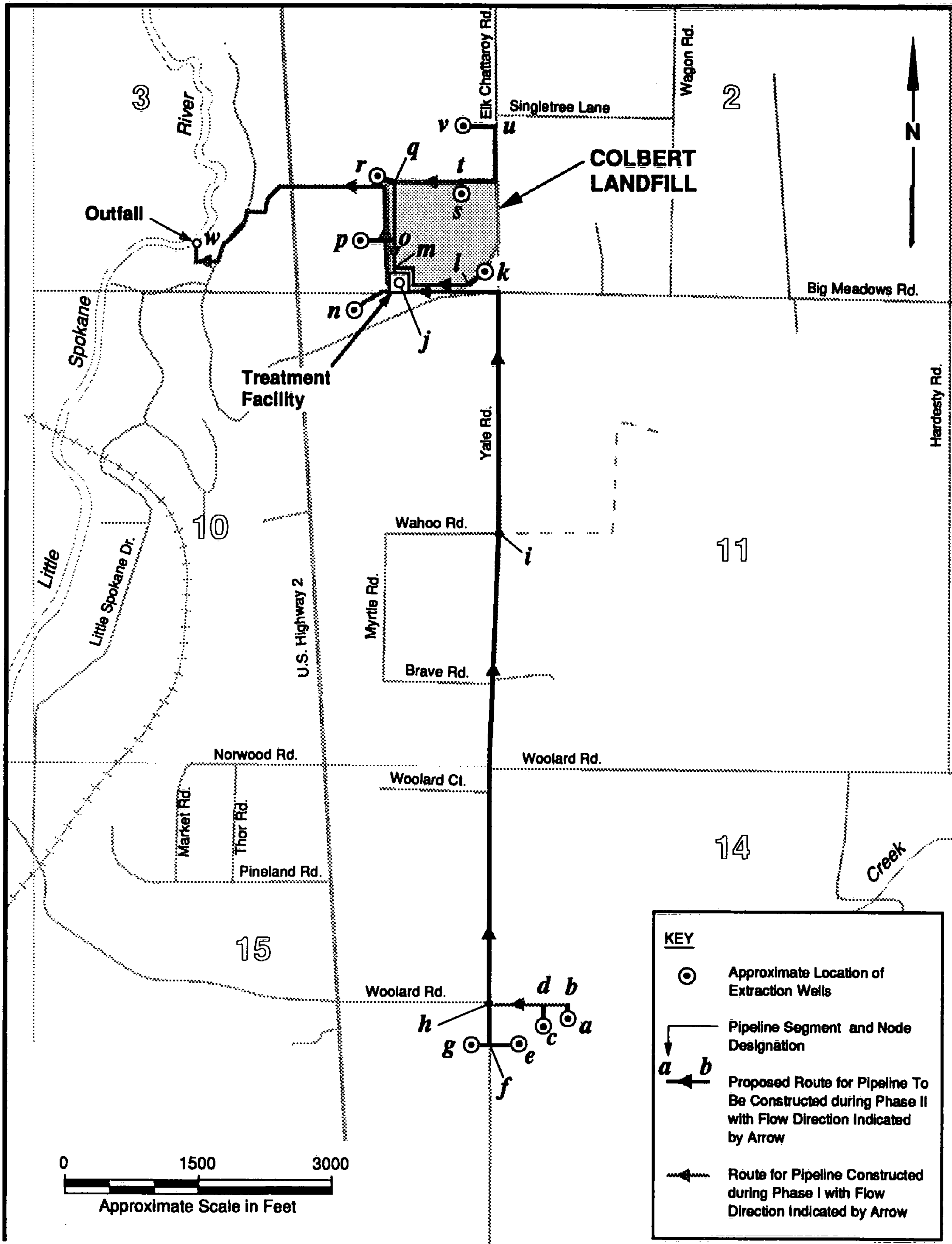
- Select backfill material will be placed to 12 inches above top of pipe. Select backfill material shall consist of select native material of which 100 percent shall pass a 1-½ inch square opening sieve, and shall be free of topsoil or organic matter.
- Backfill material will be placed from 12 inches above the top of pipe up to the backfill limits. Backfill shall be native material free of topsoil or organic matter and any large boulders, rocks, or chunks of consolidated earth that might damage the pipe or structure or present a compaction problem. Boulders larger than 1 ft measured in any direction shall not be used as backfill material. Six-inch minus material shall be used in the top 2 ft of the subgrade under roads and streets.

Pipe bedding material will be compacted to 90 percent of the maximum dry density determined using Modified Proctor Compaction Test procedures (ASTM 1557-78). Select backfill material and backfill material will be compacted to 85 percent maximum dry density, except 95 percent maximum dry density will be required beneath roadways. For compaction, a loose lift maximum depth of 12 inches shall be used, except that in street and road crossings the top 2 ft is limited to a loose lift depth of 4 inches. A typical pipeline trench section is shown on Figure 3-8.

The conveyance piping constructed during Phase I (as shown on Figure 3-1) was completed in general accordance with the design standards presented in this section. All conveyance, other than for the Highway 2 crossing, is PVC SDR26 Class 160 pipe. The Highway 2 crossing was constructed with ductile iron pipe. Backfill material generally meet the material and compaction specifications described in this section. As-built drawings for pipelines constructed during Phase I will be submitted with the Phase II construction documentation report.

3.5 OUTFALL STRUCTURE

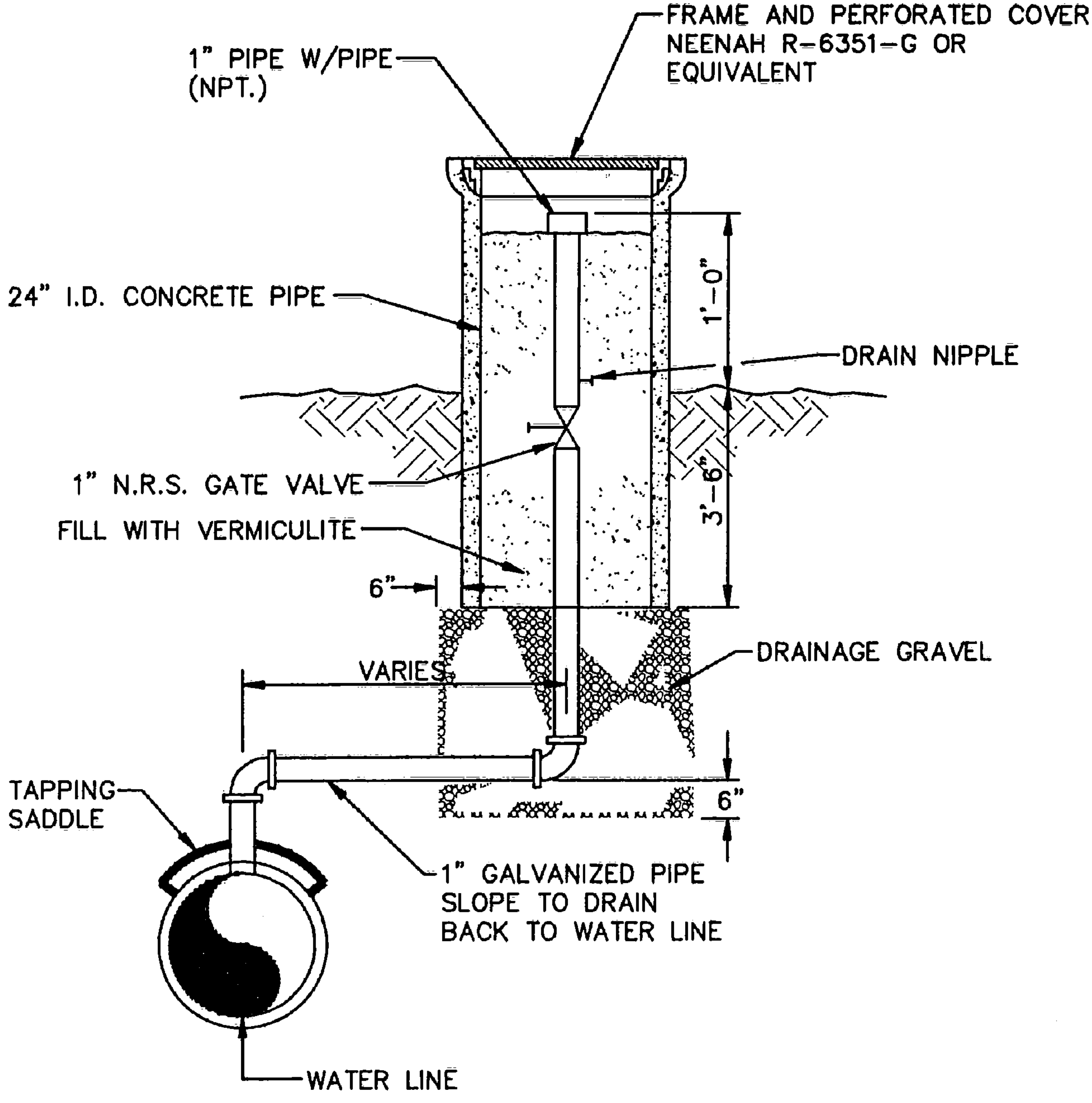
The Little Spokane River outfall was constructed during Phase I and will be used for Phase II operation. The outfall includes an energy dissipater consisting of a 2,500-gallon subsurface concrete vault with a partial internal divider. Flow from the vault is by gravity via an 18-inch diameter PVC pipe (SDR35 ASTM 3034 pipe) to a riprap-lined outfall to the Little Spokane River. Figure 3-9 shows the general configuration of this discharge structure. It is anticipated that this discharge structure will function adequately for Phase II, although a steel plate may be mounted on the internal divider for erosion protection.



Phase II Pipeline Design Schematic

Figure 3-1

124001.73 Spokane Co./Colbert Landfill/ RD/RA Phase II/Final Treatment & Discharge Plan 3/92

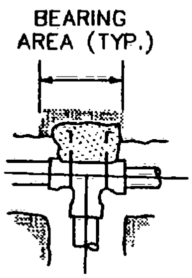


Source: Taylor Engineering (1993)

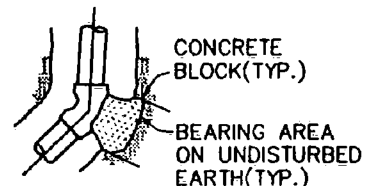
124001.73 Spokane Co./Colbert Landfill/ RD/RA Phase II /Final Treatment & Discharge Plan 2/93

Test Connection	Figure 3-2

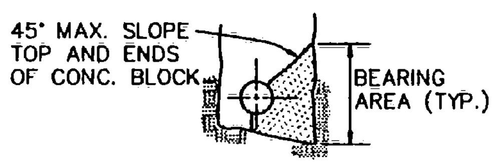
FITTING SIZE	MINIMUM BEARING AREA OF THUST BLOCK IN SQUARE FEET				
	90° BEND	45° BEND	22 1/2° BEND	11 1/4° BEND	TEE ENDS
4	1.9	1.1	.5	.3	1.9
6	4.0	2.3	1.2	.7	4.0
8	7.2	3.9	2.0	1.1	7.2
10	11.2	6.1	3.1	1.6	11.2
12	16.0	8.8	4.4	2.4	16.0



TYPICAL TEE



HORIZONTAL ELBOW



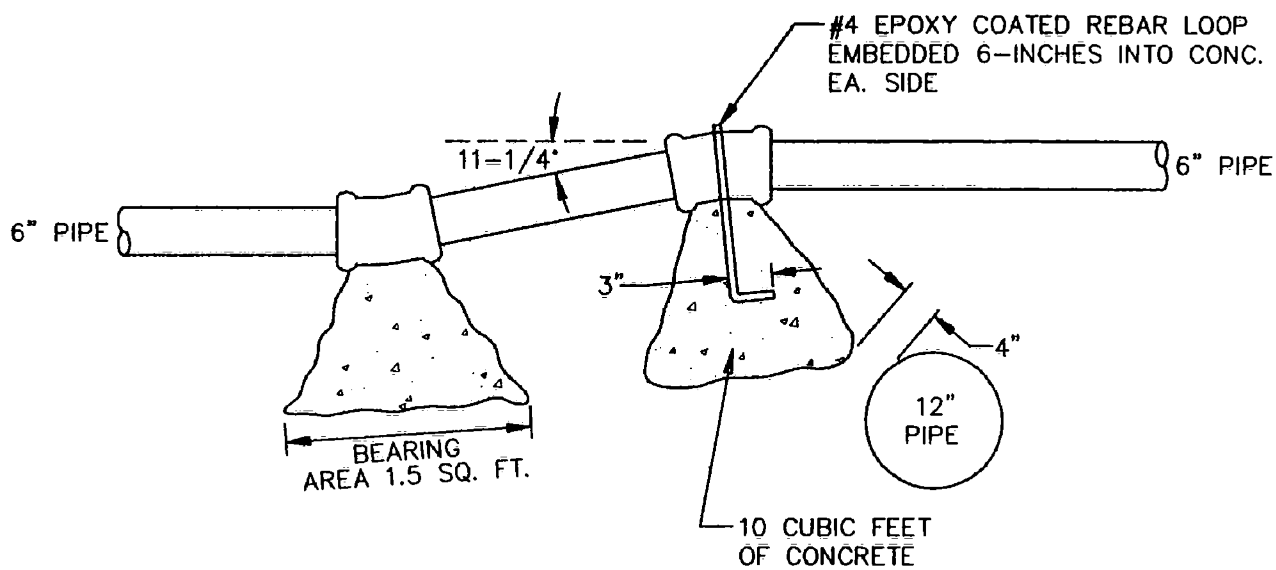
SECTION OF THRUST BLOCK

NOTES:

1. KEEP CONCRETE CLEAN OF JOINT AND JOINT ACCESSORIES.
2. THE REQUIRED THRUST BLOCK AREAS FOR SPECIAL CONDITIONS ARE SHOWN ON THE DRAWINGS.
3. REQUIRED AREAS AT FITTINGS SHALL BE AS INDICATED BELOW. HORIZONTAL BENDS IN ABOVE TABLE.
4. THIS TABULATION IS BASED UPON A MAXIMUM WATER PRESSURE OF 200 p.s.i. AND A SAFE BEARING CAPACITY OF 2000lbs./Sq.Ft. ADJUST BEARING AREA PROPORTIONATELY FOR OTHER VALUES OF PRESSURE AND ALLOWABLE BEARING CAPACITY.

Source: Taylor Engineering (1993)

Thrust Block Layout for Horizontal Pressures | Figure 3-3



Source: Taylor Engineering (1993)

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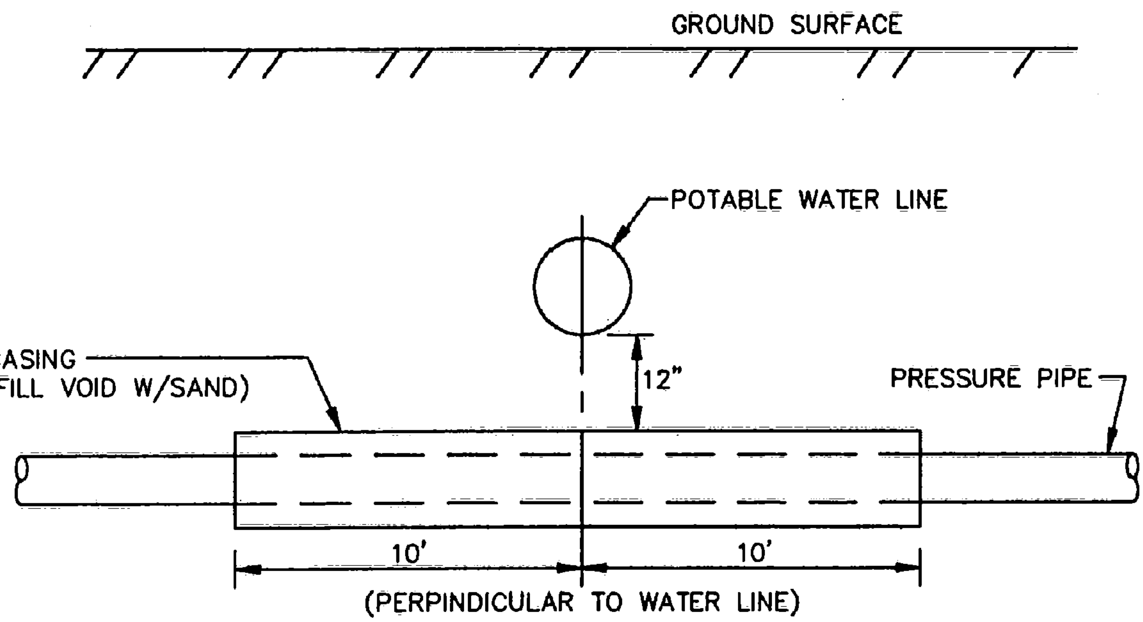
Vertical Thrust Block Detail	Figure 3-4

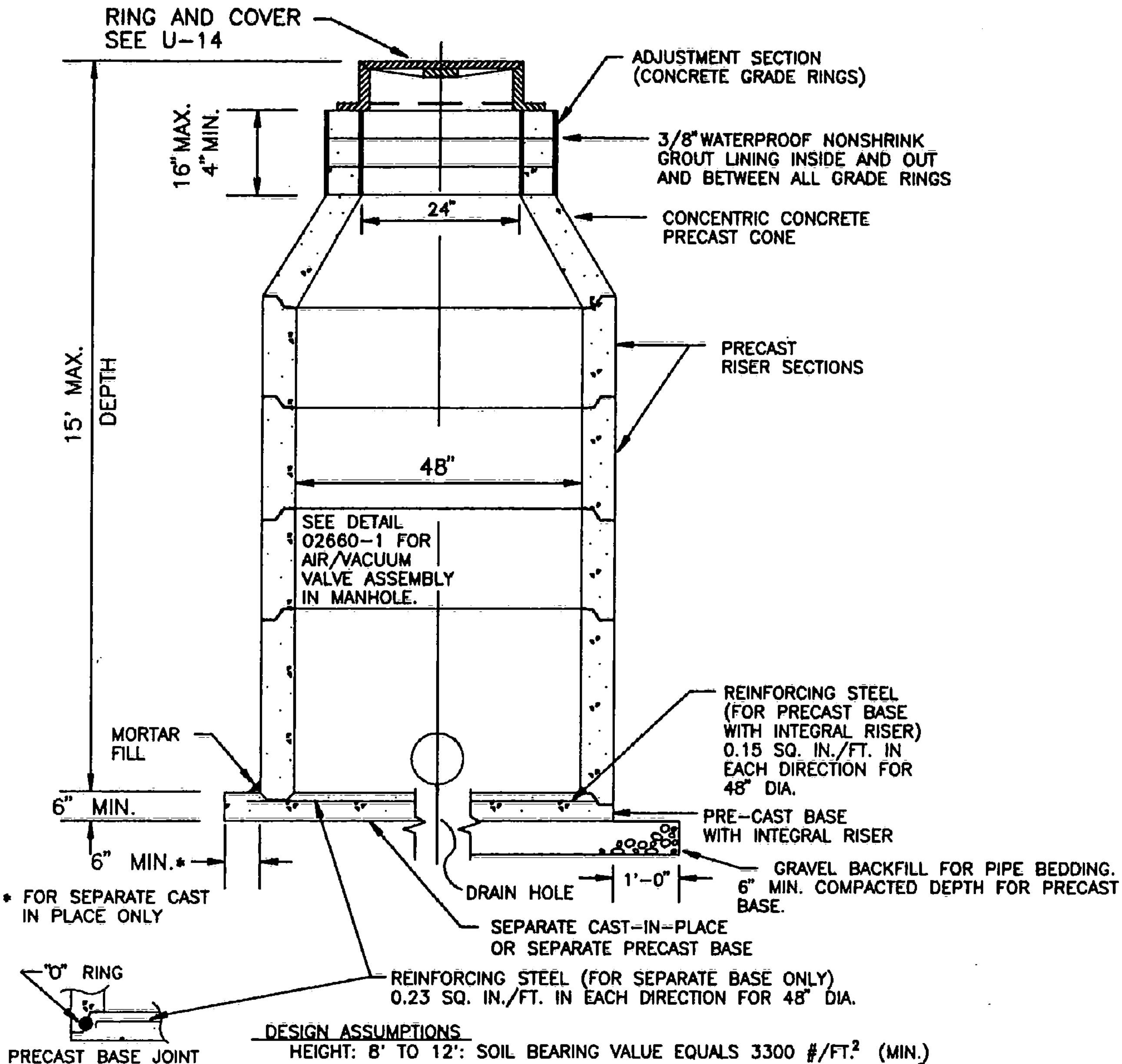
124001.73 Spokane Co./Colbert Landfill/ RD/RA Phase II /Final Treatment & Discharge Plan 2/93



Source: Taylor Engineering (1993)

Potable Water Line Crossing

Figure 3-5



DESIGN ASSUMPTIONS

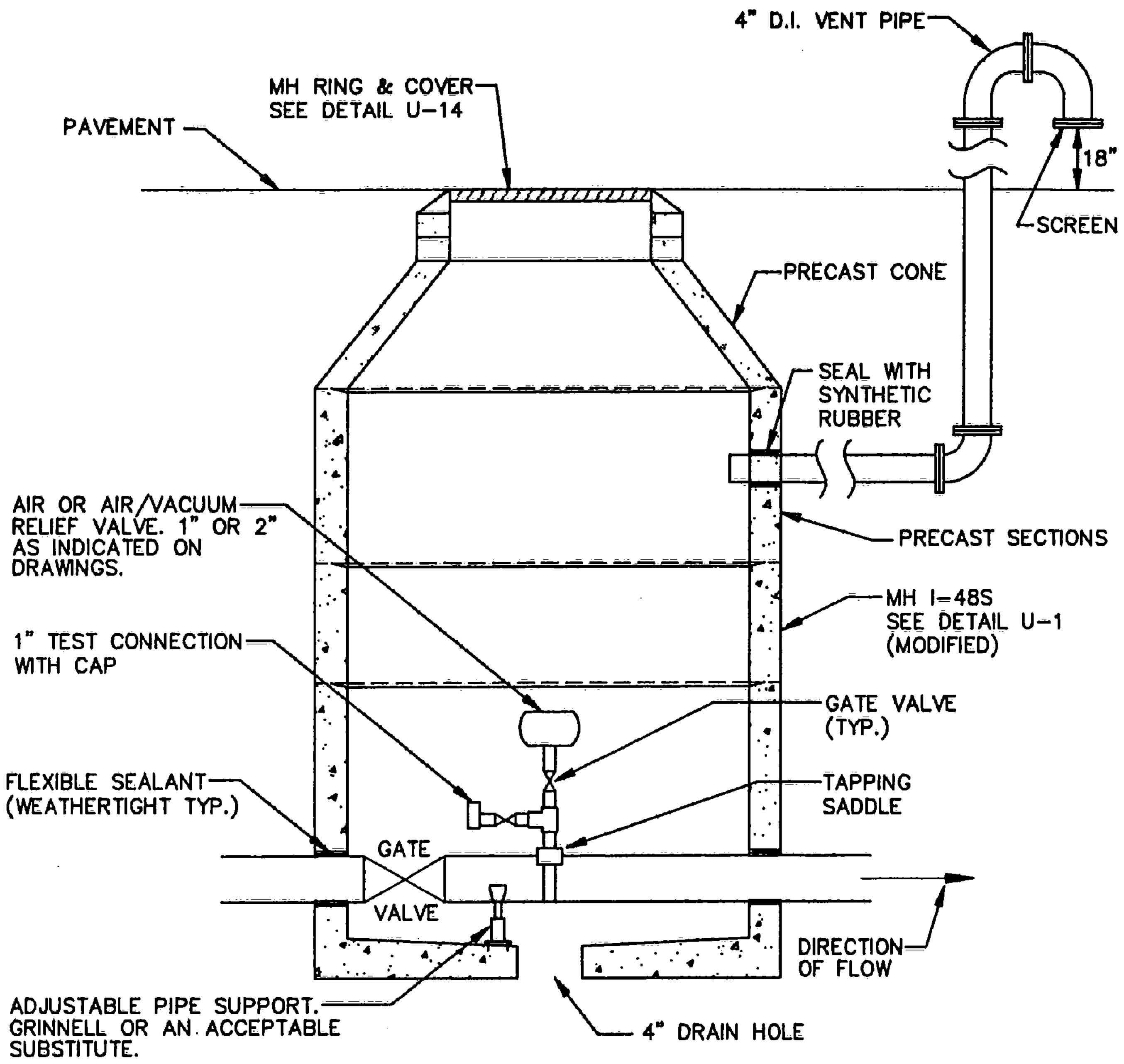
HEIGHT: 8' TO 12': SOIL BEARING VALUE EQUALS 3300 #/FT.^{2} (MIN.)
HEIGHT: OVER 12' TO 15': SOIL BEARING VALUE EQUALS 3800 #/FT.^{2} (MIN.)

NOTES

1. MANHOLES TO BE CONSTRUCTED IN ACCORDANCE WITH AASHTO M-199 (ASTM C 478) UNLESS OTHERWISE SHOWN ON PLANS OR NOTED IN THE STANDARD SPECIFICATIONS, AND IN ACCORDANCE WITH WSDOT SEC 6-02.3.
2. ALL REINFORCED CAST IN PLACE CONCRETE SHALL BE CLASS A. NON-REINFORCED CONCRETE IN CHANNEL AND SHELF SHALL BE CLASS C. ALL PRECAST CONCRETE SHALL BE CLASS AX.
3. PRECAST BASES SHALL BE FURNISHED WITH CUTOUTS OR KNOCKOUTS. KNOCKOUTS SHALL HAVE A WALL THICKNESS OF 2" MINIMUM.
4. KNOCKOUT OR CUTOUT HOLE SIZE IS EQUAL TO PIPE OUTER DIAMETER PLUS MANHOLE WALL THICKNESS. MAXIMUM PIPE SIZE IS 21" FOR 48" MANHOLE. (MAX. PIPE SIZE MAY BE LIMITED BY PIPE CONFIGURATION.) MINIMUM DISTANCE BETWEEN HOLES IS 8".
5. ALL BASE REINFORCING SHALL HAVE A MINIMUM YIELD STRENGTH OF 60,000 PSI AND BE PLACED IN THE UPPER HALF OF THE BASE WITH 1" MINIMUM CLEARANCE.
6. NO STEPS SHALL BE PLACED.
7. PROVIDE 4-INCH DIA. DRAIN HOLE IN BOTTOM SLAB AND 1/2 CU. YD. OF DRAINAGE ROCK BELOW SLAB.

Source: Taylor Engineering (September 8, 1990)

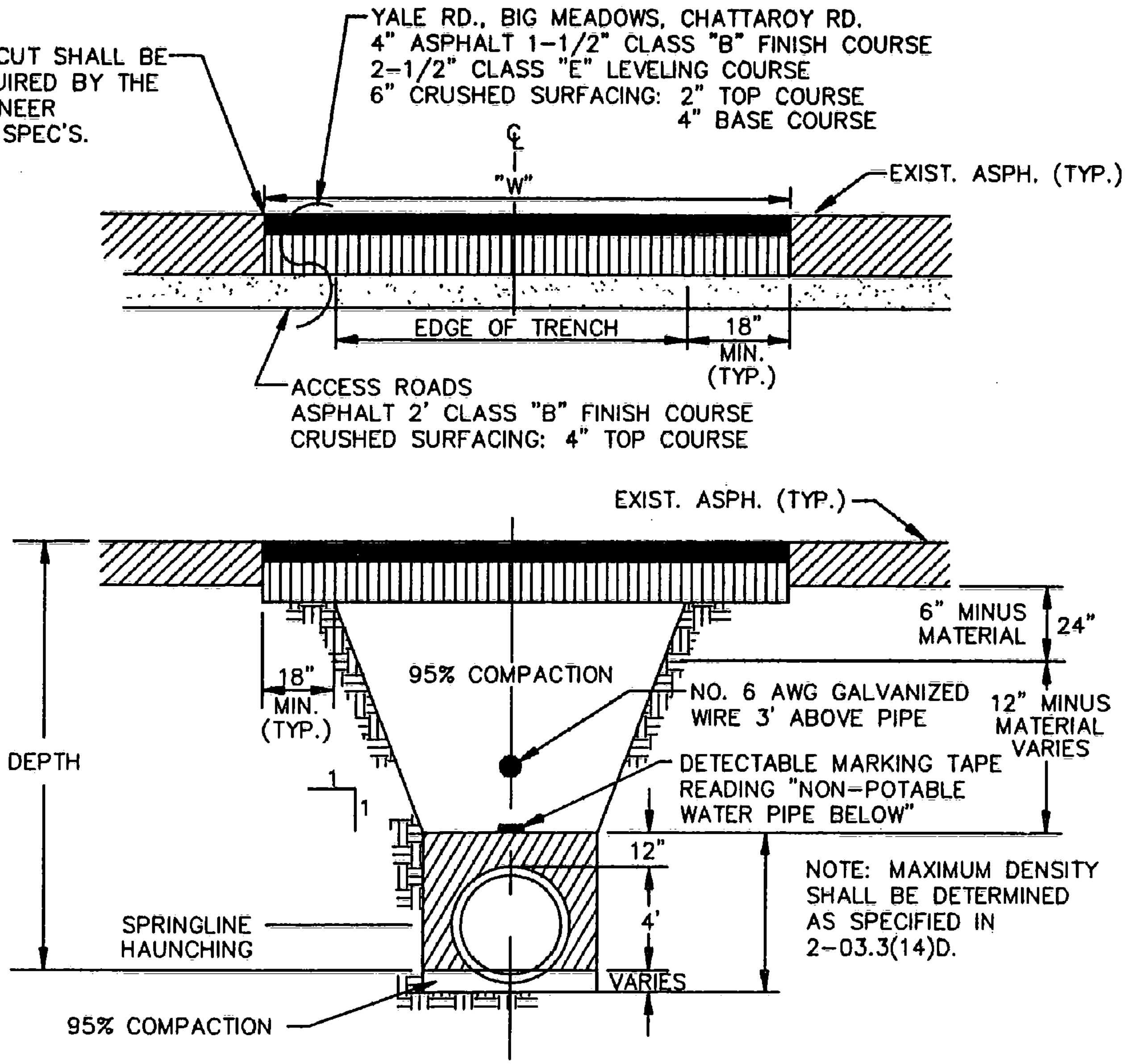
Manhole Type I-48S	Figure 3-6



Source: Taylor Engineering (1993)

124001.73 Spokane Co./Colbert Landfill/ RD/RA Phase II /Final Treatment & Discharge Plan 2/93

Air and Vaccum Relief Valves with Test Connections	Figure 3-7



<u>RIGID PIPE</u> – CLASS B BEDDING ①
<u>FLEXIBLE PIPE</u> – CLASS F BEDDING ①

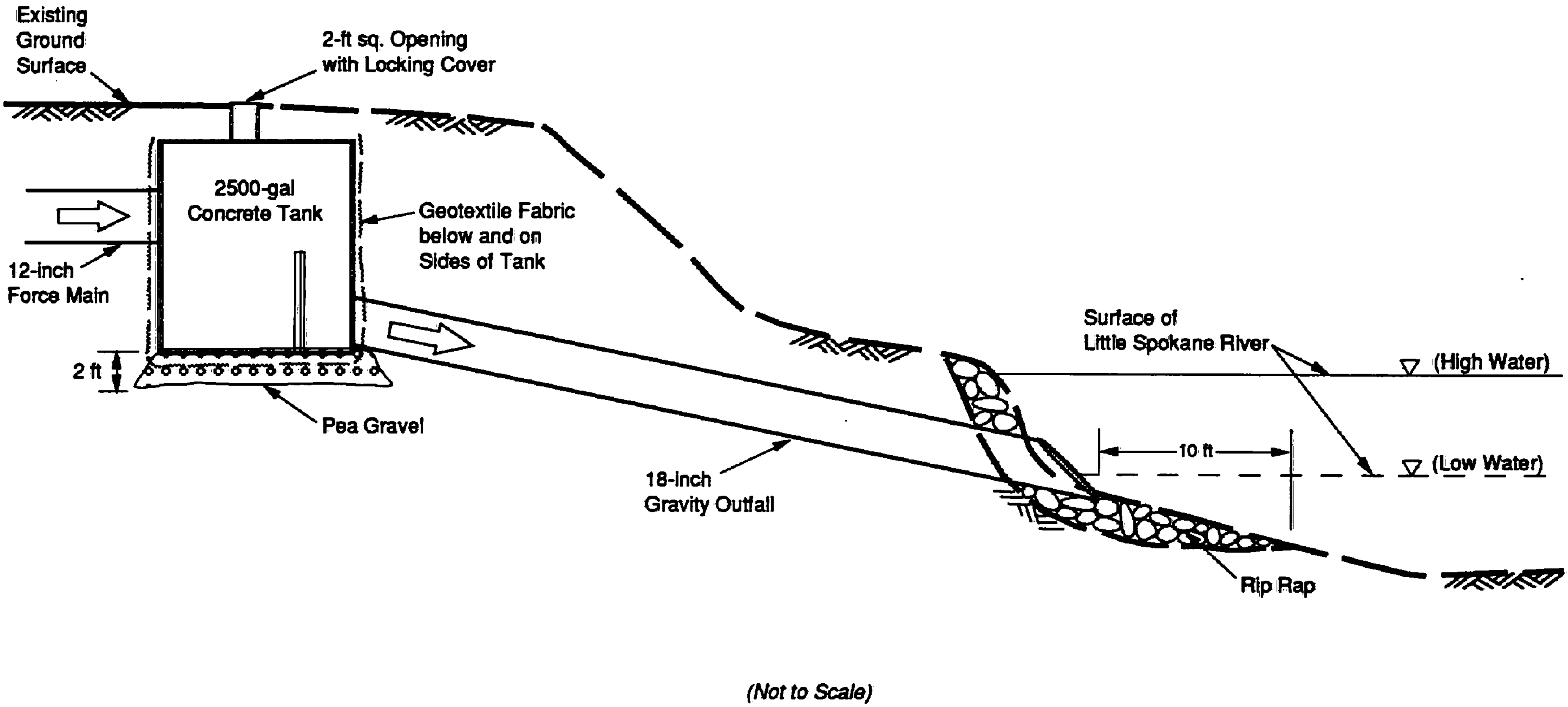
NOTES:

1. BEDDING COMPOSED OF ONSITE MATERIAL SHALL BE CONSIDERED INCIDENTAL. PAYMENT FOR IMPORT BEDDING IF REQUIRED SHALL BE AT A NEGOTIATED TONNAGE BASIS.
   SEE U-19 FOR BEDDING REQUIREMENTS

Source: Taylor Engineering (1993)

Trench Compaction

Figure 3-8



Source: Taylor Engineering (1991)

Little Spokane River Outfall Section

Figure 3-9

TABLE 3-1

PHASE II PIPELINE DESIGN DIAMETERS AND VELOCITIES

Pipeline Segment	Maximum Design Discharge (gpm)	Pipeline Design Diameter (inches)	Design Velocity[a] (ft/sec)
a-b	150	4	4.2
b-d[b]	300	8	2.0
c-d	150	4	4.2
d-h[b]	400	8	2.7
e-f	100	4	2.8
g-f	100	4	2.8
f-h	400	6	4.5
h-i	400	8	2.7
i-j[c]	700	8	4.8
k-l[b]	4	2	0.4
l-m	200	6	2.3
n-j[b]	350	6	4.0
m-j	1050	10	4.8
o-m[b]	850	8	5.8
p-o	350	6	4.0
q-o[b]	850	8	5.8
r-q	250	6	2.8
t-q[b]	700	8	4.8
s-t	200	4	5.7
u-t	500	8	3.4
v-u	200	6	2.3
j-w	1600	12	4.5

(a) Design velocity = (maximum design discharge)/(pipeline cross sectional area).
(b) Pipeline constructed during Phase I.
(c) Pipeline segment from Elk-Chatteroy Road to treatment facility constructed during Phase I.

TABLE 3-2

ESTIMATED MAXIMUM OPERATING, WATER HAMMER, AND TOTAL PIPE PRESSURES

Pipeline	Estimated Maximum Operating Pressure (psi)	Estimated Maximum Water Hammer Pressure (psi)	Estimated Maximum Total Pipe Pressure (psi)
CP-S1, CP-S4, CP-S5, CPS6	70	65	135
CP-E1, EP-E2, CP-E3, CP-W2, CP-W3	70	79	149
CP-W1	40	57	97

4.0 IMPLEMENTATION/QUALITY ASSURANCE

4.1 TREATMENT SYSTEM

4.1.1 Implementation

The implementation plan for the treatment and discharge systems includes two phases: 1) bidding and fabrication of the air stripping tower and 2) bidding and construction of the treatment and discharge systems, including installation of the air stripping tower, scale control systems, and conveyance piping. Two design bid packages will be prepared: 1) performance specification for the air stripping system, and 2) construction plans and specification for all treatment and discharge facilities, including installation of the air stripping tower system.

Procurement of the air stripping tower system is underway, and the system supplier will be selected prior to the completion of the construction plans and specifications. The final design details for the air stripping system will be submitted in the form of shop drawings by the selected supplier. These shop drawings will be submitted to EPA and Ecology in the Construction Documentation Report.

Construction of the site facilities will commence upon bidding and selection of a contractor. Site construction activities will commence concurrently with fabrication of the air stripping tower system, and completion of these facilities will be scheduled to support installation of the stripping tower upon its delivery. Major site facilities to be constructed during this phase include the extraction well systems, operation and control systems, conveyance piping, foundations and structures, the treatment system building and influent manifold, and scale control process equipment.

A draft operations and maintenance plan will be prepared during the design phase, and will be finalized upon completion of the construction phase to reflect constructed facilities. As-built drawings of the constructed facilities will be prepared for inclusion in the operations and maintenance manual.

Equipment startup will commence upon completion of construction. The system startup will include functional testing and calibration of installed equipment, adjustment of system operating parameters, testing, and calibration of instrumentation; monitoring of influent and effluent quality from the treatment system; and operator training. An operator training section will be included in the operations and maintenance plan, and training will be conducted by both the equipment suppliers and the design consultant. All laboratory analysis for startup monitoring will be performed in accordance with the QAPjP (Landau Associates 1992d).

4.1.2 Construction Quality Assurance

Construction quality assurance will be implemented in general accordance with the EPA document *Superfund Remedial Design and Remedial Action Guidance* (EPA 1986). This document outlines relevant quality assurance tasks to be undertaken during construction of remedial actions.

Specification documents will include quality assurance requirements for fabrication and construction of the treatment and discharge systems. Codes and specifications commonly referenced in construction documents will define quality assurance requirements for the various fabricated equipment and constructed facilities. Equipment data sheets for each major equipment item will require submittal by the contractor and approval by the design engineer.

Construction inspection will be conducted by a full-time inspector familiar with the specification requirements, as well as the construction techniques to be used. Fabrication of the air stripping tower system will be inspected at appropriate stages of progress, and functional testing of appropriate equipment components will be witnessed by the design engineer prior to shipment of the system to the site. Grain size analysis (ASTM D 422) will be performed on pipeline backfill material to verify conformance with material specifications. Backfill moisture-density relationships will be developed in conformance with ASTM 1557-78 test method, and conformance with backfill compaction specifications will be verified by visual inspection and field testing (ASTM D 2922 and D 1556).

A full-time construction inspector will be resident during all onsite Phase II construction activities. This inspector will maintain records and reports during these activities for documentation of the remedial action. The inspector will be responsible for documentation of conformance of construction to the specifications, and shall be authorized to stop activities not in compliance with specification requirements. Periodic progress status reports will be prepared to document and report Project construction activities. The inspector will be responsible for coordination of both prefinal and final construction inspection conferences with the appropriate regulatory agencies.

Upon completion of the final construction inspection, a construction documentation report will be prepared to document construction of the Phase II remedial action. This report will include a synopsis of the work conducted, as-built construction drawings, explanation of significant modifications from the design (if any), and documentation of the startup of the remedial action. The construction documentation report will be submitted to EPA and Ecology for final documentation of Phase II remedial action construction.

5.0 NPDES DISCHARGE WATER QUALITY CHARACTERIZATION

Section XXI of the Project Consent Decree specifies that no Federal, State, or local permit shall be required for portions of the remedial action conducted entirely on the Site, although compliance with the substantive requirements of applicable Federal laws is required. The National Pollutant Discharge Elimination System (NPDES) program, promulgated under the Clean Water Act (33 USC 1251), includes substantive monitoring and reporting requirements applicable to operation of the remedial action. This section provides anticipated hydraulic and constituent loadings to the Little Spokane River for the Constituents of Concern, summarizes the results of NPDES-related surface water and groundwater characterization accomplished subsequent to submittal of the Preliminary Plan, and identifies remaining NPDES issues.

5.1 HYDRAULIC AND CONSTITUENT LOADINGS

As described in Section 2.1.3, hydraulic loading could range between 600 and 1,600 gpm, and is anticipated to be about 1,000 gpm. For the purposes of NPDES flow characterization, the maximum design flow rate of 1,600 gpm is used.

The SOW specifies the maximum allowable concentration of the Constituents of Concern for discharge to the Little Spokane River as the Evaluation Criteria. These concentrations define the maximum concentration allowed for discharge to the Little Spokane River during operation of the remedial action. However, the Evaluation Criteria for DCA (4,050 ppb) is much higher than the maximum concentration of DCA observed in groundwater samples collected during Phase I (180 ppb), so the maximum DCA concentration detected during Phase I will be used for NPDES constituent loading purposes.

The anticipated maximum constituent loadings to the Little Spokane River for the Constituents of Concern are presented in Table 5-1. Both concentration and daily mass loadings are provided. Daily mass loadings are based on a flow rate of 1,600 gpm.

5.2 NPDES WATER QUALITY CHARACTERIZATION

Ecology-requested characterization of water quality for NPDES purposes included sampling and analysis of representative groundwater monitoring wells and surface water from the Little Spokane River. Groundwater samples were collected at the site on July 21-22, 1992, from groundwater Monitoring Wells CD-21C1, CD-30A, CD-46C2, and CD-47C2. A surface water sample was collected from the Little Spokane River on July 22, 1992 at the proposed Phase II outfall location.

All groundwater samples were analyzed for Ecology-requested constituents, including metals (total and dissolved), inorganic/conventional parameters, organochlorine pesticides/PCBs, organophosphorus pesticides, and herbicides. Because no semivolatile compounds were detected in the sample from Monitoring Well CD-21C1, and groundwater in the Monitoring Well CD-21C1 vicinity is anticipated to have the highest impact from the Colbert Landfill, samples from other wells were not analyzed for these compounds. The sample collected from the Little Spokane River was analyzed for total metals, inorganics/conventionals, organochlorine pesticides/PCBs, organophosphorus pesticides, herbicides, and other parameters.

Groundwater and surface water samples were also analyzed for selected major ions at the request of Ecology in its April 28, 1992 comment letter on the Preliminary Plan. The major ions analyzed for were bicarbonate and total alkalinity, calcium, chloride, magnesium, nitrates, potassium, silicon, and sulfate. Analytical data are presented in Table 5-2.

During Phase II remedial action, groundwater from the vicinity of the sampled wells will contribute different percentages to the total effluent. It is expected that the areas surrounding the wells will contribute about the following percentages:

Monitoring Well Designation	Estimated Relative Contribution (%)
CD-21C1	15
CD-30A	33
CD-46C2	26
CD-47C2	26

The estimated combined effluent concentrations presented in Table 5-2 were calculated from individual well data using these estimated relative contributions. Constituent mass loadings (lb/day) were estimated assuming a discharge rate of 1,600 gpm, and are also presented in Table 5-2.

5.3 REMAINING NPDES ISSUES

Many of the NPDES issues identified by Ecology in its review of the Preliminary Plan were resolved by the water quality characterization described in Section 5.2. However, certain NPDES issues remain unresolved. The most significant remaining issue is the presence of phosphorus in Project effluent. Other issues include Ecology's identification of potential discharge criteria for the Constituents of Concern that are more stringent than those identified in the Project Consent Decree and identification of design criteria for constituents that will not be treated by the remedial action.

These remaining issues may significantly impact the design and construction, and/or operation of the Phase II remedial action. However, not going forward with Project design and construction until all NPDES issues are resolved could compromise the remedial action, potentially delaying construction for more than a year and increasing design and construction costs by millions of dollars. As a result, Spokane County has decided, with the concurrence of EPA and Ecology, to proceed with design and construction of the remedial action. The remaining NPDES issues will be addressed concurrently with other Project activities and resolution will be presented in an independent document.

TABLE 5-1

ESTIMATED MAXIMUM CONSTITUENT OF CONCERN LOADINGS
FOR PHASE II OPERATION

Constituents of Concern	Estimated Maximum Constituent Loading	
	Concentration[a]	Mass Loading (lb/day)[b]
Trichloroethane (TCA)	0.20	3.9
Methylene Chloride (MC)	0.025	0.5
Dichloroethene (DCE)	0.007	0.1
Dichloroethane (DCA)	0.180	3.5
Trichloroethene (TCE)	0.005	0.1
Tetrachloroethene (PCE)	0.007	0.1

(a) Report in mg/L.
(b) Based on 1,600 gpm flow rate.

TABLE 5-2
BACKGROUND WATER QUALITY DATA AND ESTIMATED EFFLUENT QUALITY
(Concentrations in ug/L-except when indicated otherwise)

Constituent	Analytical Method	CD21C1	CD47C2	CD46C2	CD46C2-DUP	CD30A	Little Spokane River	Estimated Effluent Concentration (a)	Estimated Effluent Mass Loading (b) (lb/day)
METALS (Total, in mg/l)									
Aluminum	EPA 6010	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.050 U	NC
Antimony	EPA 6010	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	NC
Arsenic	EPA 7060	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Arsenic (pent)	EPA 7060	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Arsenic (tri)	EPA 7060	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Barium	EPA 6010	0.271	0.079	0.292	0.297	0.114	0.052	0.17	3.4
Beryllium	EPA 6010	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Cadmium	EPA 6010	0.003 U	0.003 U	0.003 U	0.003 U	0.003 U	0.003 U	0.003 U	NC
Calcium	EPA 6010	172	60.6	140	143	104	30.3	112	2200
Chromium (hex)	EPA 7195/6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NC
Chromium (total)	EPA 6010	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Copper	EPA 6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NC
Iron	EPA 6010	0.033	0.02 U	0.065	0.068	0.02 U	0.099	0.034	0.65
Lead	EPA 7421	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	NC
Magnesium	EPA 6010	60.3	19.5	48.6	49.5	22.5	7.37	34	660
Manganese	EPA 6010	0.014	0.005 U	0.077	0.078	0.005 U	0.018	0.025	0.48
Mercury	EPA 7470	0.0005 U	0.0005 U	0.0005 U	0.0005 U	0.0005 U	0.0005 U	0.0005 U	NC
Nickel	EPA 6010	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	NC
Potassium	EPA 6010	4.9	2.9	3.8	4.1	3.3	2 U	3.6	70
Selenium	EPA 7740	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Silicon	EPA 6010	12.9	11.5	12.3	2.6	9.64	8.34	11.3	220
Silver	EPA 6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NC
Thallium	EPA 7841	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NC
Zinc	EPA 6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.19
METALS (Dissolved, in mg/l)									
Aluminum	EPA 6010	0.056	0.05 U	0.05 U	0.055	0.05 U	NT	0.051	NC
Antimony	EPA 6010	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	NT	0.050 U	NC
Arsenic	EPA 7060	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NT	0.005 U	NC
Arsenic (pent)	WF	NT	NT	NT	NT	NT	NT	NC	NC
Arsenic (tri)	WF	NT	NT	NT	NT	NT	NT	NC	NC
Barium	EPA 6010	0.269	0.081	0.301	0.303	0.111	NT	0.176	NC
Beryllium	EPA 6010	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NT	0.005 U	NC
Cadmium	EPA 6010	0.003 U	0.003 U	0.003 U	0.003 U	0.003 U	NT	0.003 U	NC
Calcium	EPA 6010	171	62.4	144	145	102	NT	113	NC
Chromium (hex)	EPA 7195/6010	NT	NT	NT	NT	NT	NT	NC	NC
Chromium (total)	EPA 6010	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NT	0.005 U	NC
Copper	EPA 6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NT	0.010 U	NC
Iron	EPA 6010	0.033	0.02 U	0.05	0.051	0.02 U	NT	0.030	NC
Lead	EPA 7421	0.002 U	0.002 U	0.002 U	0.002 U	0.002 U	NT	0.002 U	NC
Magnesium	EPA 6010	59.8	20.7	49.4	50	22	NT	34.5	NC
Manganese	EPA 6010	0.014	0.005 U	0.075	0.077	0.005 U	NT	0.025	NC
Mercury	EPA 7470	0.0005 U	0.0005 U	0.0005 U	0.0005 U	0.0005 U	NT	0.000 U	NC
Nickel	EPA 6010	0.02 U	0.02 U	0.02 U	0.02 U	0.02 U	NT	0.020 U	NC
Potassium	EPA 6010	5	3.3	4	3.8	3.3	NT	3.74	NC
Selenium	EPA 7740	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NT	0.005 U	NC
Silicon	EPA 6010	12.8	11.9	12.5	12.7	9.41	NT	11.37	NC
Silver	EPA 6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NT	0.010 U	NC
Thallium	EPA 7841	0.005 U	0.005 U	0.005 U	0.005 U	0.005 U	NT	0.005 U	NC
Zinc	EPA 6010	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NT	0.01 U	NC

TABLE 5-2
BACKGROUND WATER QUALITY DATA AND ESTIMATED EFFLUENT QUALITY
(Concentrations in ug/L-except when indicated otherwise)

Constituent	Analytical Method	CD21C1	CD47C2	CD46C2	CD46C2-DUP	CD30A	Little Spokane River	Estimated Effluent Concentration (a)	Estimated Effluent Mass Loading (b) (lb/day)
INORGANICS/CONVENTIONALS									
Alkalinity (mg/L)	EP 310.1	642	221	554	556	325	107	405	7800
Ammonia (total as N) (mg/L)	EP 350.3	0.07	0.05 U	0.05 U	0.05 U	0.05 U	0.05 U	0.053	NC
Bicarbonate Alkalinity(mg/L)	SM 2320B	642	221	554	556	325	104	405	7800
BOD (mg/L)	EP 405.1	4 U	4 U	4 U	4 U	4 U	4 U	4 U	NC
COD (mg/L)	EP 410.2	5 U	5 U	5 U	5 U	5 U	10	5 U	NC
Chloride (mg/L)	EP 300.0	7.2	3.9	270	290	300	340	171	3300
Chlorine-Residual (mg/L)	EP 330.4	0.1 UJ	0.1 UJ	0.1 UJ	0.1 UJ	0.1 UJ	0.1 UJ	0.1 U	NC
Coliform Fecal (CFU/100mL)	SM 9221C	2 UJ	2 UJ	2 UJ	2 UJ	2 UJ	50 J	2 U	NC
Color (CU)	EP 110.2	20 U	20 U	20 U	20 U	20 U	20 U	20 U	NC
Cyanide (mg/L)	EP 335.2	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	0.01 U	NC
Gases, Total Dissolved	N/A (c)	NT	NT	NT	NT	NT	NT	NC	NC
Hardness (mg/L)	EPA 6010	673	241	563	568	344	106	423	8100
Nitrates (mg/L)	EP 300.0	1.4	5.1	2.8	2.8	2.9	0.6	3.2	62
Oil and Grease (mg/L)	EP 413.1	1 U	1 U	1 U	1 U	1 U	1 U	1 U	NC
Oxygen Dissolved (mg/L)	EP 360.1	1.6 J	7.3 J	4.00 J	3.70 J	8.20 J	8.25 J	5.9	NC
pH (d)	EP 150.1	6.7	7.7	7.2	7.2	7.1	8.5	7.2	NC
Phosphorus-Total (mg/L)	EP 365.3	0.24	1.6	0.50	0.50	0.01 U	0.02	1.1 (d)	22
Solids Suspended - Nonfilterable (mg/L)	EP 160.2	5 U	5 U	5 U	5 U	5 U	5 U	5 U	NC
Solids Dissolved - Filterable (mg/L)	EP 160.1	677	295	591	597	368	127	453	8700
Sulfate (mg/L)	EP 300.0	20	13	12	12	25	16	18	340
Sulfide-Hydrogen Sulfide (mg/L)	EP 376.1	2 U	2 U	2 U	2 U	2 U	2 U	2 U	NC
Temperature (°C) (e)	EP 170.1	13.1	11.9	13.9	13.9	12.1	NT	12.7	NC
TOC (mg/L)	EP 415.1	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.8	0.5 U	NC
Turbidity (NTU)	EP 180.1	0.1 U	0.2	0.6	NT	NT	NT	NC	NC
ORGANOCHLORINE PESTICIDES/ PCBs									
Aldrin	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
BHC	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Chlordane	EPA 8080	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	NC
DDT	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
DDT Metabolite (DDE)	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
DDT Metabolite (TDE)	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Dieldrin	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Endosulfan	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Endrin	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Heptachlor	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Hexachlorocyclohexane (Lindane)	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Hexachlorocyclohexane-Alpha	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
Hexachlorocyclohexane-Beta	EPA 8080	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	NC
Methoxychlor	EPA 8080	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	0.1 U	NC
PCBs	EPA 8080	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	NC
Mirex	EPA 8080	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	0.04 U	NC
ORGANOPHOSPHORUS PESTICIDES									
Chlorpyrifos	EPA 8141	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	NC
Demeton	EPA 8141	1 U	1 U	1 U	1 U	1 U	1 U	1 U	NC
Guthion	EPA 8141	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	NC
Malathion	EPA 8141	0.5 UJ	0.5 UJ	0.5 UJ	0.5 UJ	0.5 UJ	0.5 UJ	0.5 U	NC
Parathion-methyl	EPA 8141	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	0.5 U	NC
HERBICIDES									
Chlorophenoxy Herbicides (2,4,5,-TP)	EPA 8150	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	0.2 U	NC
Chlorophenoxy Herbicides (2,4,-D)	EPA 8150	1 U	1 U	1 U	1 U	1 U	1 U	1 U	NC

TABLE 5-2
BACKGROUND WATER QUALITY DATA AND ESTIMATED EFFLUENT QUALITY
(Concentrations in ug/L-except when indicated otherwise)

Constituent	Analytical Method	CD21C1	CD47C2	CD46C2	CD46C2-DUP	CD30A	Little Spokane River	Estimated Effluent Concentration (a)	Estimated Effluent Mass Loading (b) (lb/day)
SEMIVOLATILE ORGANICS									
Acenapthene	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Benzidine	EPA 8270	50 U	NT	NT	NT	NT	NT	50 U	NC
Chlorinated Benzenes (f)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Chlorinated Napthalenes (g)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Chloroethyl Ether (bis-2)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Chloroisopropyl Ether (bis-2)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Chloromethyl Ether (bis)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Chlorophenol 2	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Chloro-4,Methyl-3,Phenol	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dibutyl Phthalate	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dichlorobenzenes (h)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dichlorobenzidine 3,3	EPA 8270	20 U	NT	NT	NT	NT	NT	20 U	NC
Dichlorophenol 2,4	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Diethylphthalate	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dimethyl Phenol 2,4	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dimethyl Phthalate	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dinitrotoluene 2,4	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Dinitro-o-cresol 2,4	EPA 8270	20 U	NT	NT	NT	NT	NT	20 U	NC
Diphenylhydrazine 1,2	EPA 8270	20 U	NT	NT	NT	NT	NT	20 U	NC
Di-2-Ethyl Hexyl Phthalate	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Fluoranthene	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Hexachlorobenzene	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Hexachlorobutadiene	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Hexachlorocyclopentadiene	EPA 8270	10 U	NT	NT	NT	NT	NT	10 U	NC
Hexachloroethane	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Isophorone	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Naphthalene	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Nitrobenzene	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Nitrophenols (i)	EPA 8270	50 U	NT	NT	NT	NT	NT	50 U	NC
Nitrosodibutylamine N	EPA 8270	10 U	NT	NT	NT	NT	NT	10 U	NC
Nitrosodiethylamine N	EPA 8270	10 U	NT	NT	NT	NT	NT	10 U	NC
Nitrosodimethylamine N	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Nitrosodiphenylamine N	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Nitrosopyrrolidine N	EPA 8270	10 U	NT	NT	NT	NT	NT	10 U	NC
Pentachlorobenzene	EPA 8270	10 U	NT	NT	NT	NT	NT	10 U	NC
Pentachlorophenol	EPA 8270	30 U	NT	NT	NT	NT	NT	30 U	NC
Phenol	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Phthalate Esters (j)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Polynuclear Aromatic Hydrocarbons (k)	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Tetrachlorobenzene 1,2,4,5	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Trichlorophenol 2,4,5	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
Trichlorophenol 2,4,6	EPA 8270	5 U	NT	NT	NT	NT	NT	5 U	NC
VOLATILE ORGANICS (l)									
1,1-Dichloroethane	EPA 8010	NT	NT	NT	NT	NT	NT	180 (m)	3.5
1,1-Dichloroethylene	EPA 8010	NT	NT	NT	NT	NT	NT	7.0 (m)	0.13
Methylene chloride	EPA 8010	NT	NT	NT	NT	NT	NT	25 (m)	0.48
Tetrachloroethylene	EPA 8010	NT	NT	NT	NT	NT	NT	7.0 (m)	0.13
Trichloroethane 1,1,1	EPA 8010	NT	NT	NT	NT	NT	NT	200 (m)	3.8
Trichloroethylene	EPA 8010	NT	NT	NT	NT	NT	NT	5 (m)	0.1

TABLE 5-2
BACKGROUND WATER QUALITY DATA AND ESTIMATED EFFLUENT QUALITY
(Concentrations in ug/L-except when indicated otherwise)

Constituent	Analytical Method	CD21C1	CD47C2	CD46C2	CD46C2-DUP	CD30A	Little Spokane River	Estimated Effluent Concentration (a)	Estimated Effluent Mass Loading (b) (lb/day)
MISCELLANEOUS									
Acrolein	EPA 8240	10 U	10 U	10 U	10 U	10 U	10 U	10 U	NC
Acrylonitrile	EPA 8240	100 U	100 U	100 U	100 U	100 U	100 U	100 U	NC

Analytical Methods

EPA SW-846 Test Methods for Evaluating Solid Waste, 1986 with 1987 revisions.
EPA 6010 = Inductively Coupled Plasma Atomic Emission Spectroscopy
EPA 7195 = Chromium, Hexavalent (Coprecipitation)
EPA 8010 = Halogenated Volatile Organics.
EPA 8030 = Acrolein, Acrylonitrile, Acetonitrile.
EPA 8080 = Organochlorine Pesticides and PCBs.
EPA 8141 = Organophosporus Pesticides.
EPA 8150 = Chlorinated Herbicides.
EPA 8240 = GC/MS for Volatile Organics
EPA 8270 = GC/MS for Semivolatile Organics
EPA 8290 = Dibenzo-p-dioxins and furans.
EPA 9010 = Cyanide
WF = Walter Ficklin, U.S.G.S. "Separation of As(III) and As(V) in Groundwater".
EP = Methods of Chemical Analysis of Water and Wastes, EPA 1983.
SM = Standard Methods.

Abbreviations and Data Qualifications:

°C = Degrees Centigrade.
ml = milliliter.
NC = Not calculated.
NT = Not tested.
NTU = Nephelometric turbidity units.
U = Undetected at the detection limit given.
J = The analyte was analyzed and positively identified, but the associated numerical value may not be consistent with the amount actually present in the environmental sample.
UJ = The analyte was anlyzed for and was not present above the associated value. The associated value may not accurately or precisely represent the concentration necessary to detect the analyte in this sample.
< = The constituent was less than the associated calculated value. The associated value may not accurately or precisely represent the concentration necessary to detect the analyte in this sample.

Footnotes:

(a) This is a calculated value based on the estimated contribution of groundwater to the Phase II system from the vicinity of the sampled wells, and discharge of the batch cleaning solution. The concentration estimate is based on a total extraction rate of 1,600 gpm, with contributions of 15%, 33%, 26%, and 26% for Wells CD-21C1, CD-30A, CD-46C2, and CD-47C2, respectively, and a 0.1 gpm discharge rate of the batch cleaning solution.
(b) Based on effluent discharge rate of 1,600 gpm at the estimated effluent concentration.
(c) Not listed in any available method references.
(d) Includes 0.54 mg/l contribution from phosphate sequestering agent.
(e) Values are based on field results.
(f) The sum of 1,2-, 1,3-,1,4-dichlorobenzene, 1,2,4-trichlorobenzene, and hexachlorobenzene.
(g) Value is for 2-chloronaphthalene only.
(h) The sum of 1,2-, 1,3-, and 1,4-dichlorobenzene.
(i) The sum 2- and 4-nitrophenol and 2,4-dinitrophenol.
(j) The sum of dimethylphthalate, diethylphthalate, di-n-butylphthalate, butylbenzlphthalate, bis(2-ethylhexyl)phthalate and di-n-octylphthalate.
(k) The sum of carcinogenic PAH: benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, and indeno(1,2,3-cd)pyrene.
(l) Volatile organics were not tested for, with the concurrance of Ecology, because of the adequacy of existing data.
(m) Effluent discharge standards (Evaluation Criteria) from Project Consent Decree, except for 1,1-DCA (which is highest measured concentration).

6.0 REFERENCES

American Water Works Associates. 1971. *Water Quality and Treatment, A Handbook of Public Water Supplies*. 3rd edition. McGraw-Hill. New York, NY. pp. 334-335.

Golder Associates. 1987a. *Remedial Investigation (RI) Report for the Colbert Landfill, Spokane, WA. Volume I.* Prepared for Washington State Department of Ecology. May 1987.

Golder Associates. 1987b. *Feasibility Study (FS) Report for the Colbert Landfill, Spokane, WA. Volumes I and II.* Prepared for Washington State Department of Ecology. May 1987.

Landau Associates, Inc. 1991. *Final Phase I Engineering Report. Colbert Landfill Remedial Design/Remedial Action*. Spokane County, Washington. 30 December 1991.

Landau Associates, Inc. 1992a. *Preliminary Treatment and Discharge Plan, Phase II Remedial Design/ Remedial Action, Colbert Landfill, Spokane, WA.* 10 March 1992.

Landau Associates, Inc. 1992b. *Final Extraction Well Plan, Phase II Remedial Design/Remedial Action, Colbert Landfill, Spokane, Washington*. 10 March 1992.

Landau Associates, Inc. 1992c. *Final Groundwater Monitoring Plan, Phase II Remedial Design/ Remedial Action, Colbert Landfill, Spokane, Washington.* 7 August 1992.

Landau Associates, Inc. 1992d. *Quality Assurance Project Plan, Phase II Remedial Design/ Remedial Action, Colbert Landfill, Spokane, Washington*. 28 February 1992.

Merritt, F.S. 1983. *Standard Handbook for Civil Engineers*. 3rd edition. McGraw-Hill Book Company. New York, NY.

National Oceanic and Atmospheric Administration (NOAA). 1985. *Summary of Day-First Order TD3210, Entire Period of Record through 1985 for Spokane, Washington*. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite Data and Information Service, National Climatic Data Center, Asheville, North Carolina.

U.S. District Court, Eastern District of Washington. 1988. Consent Decree N. C-89-033-RJM. The Washington State Department of Ecology and The United States of America on behalf of the U.S. Environmental Protection Agency (plaintiffs) v. County of Spokane and Key Tronic Corporation (defendants). 28 February 1988.

U.S. Environmental Protection Agency. 1986. *Superfund Remedial Design and Remedial Action Guidance*. OSWER Directive 9355.0-4A.

U.S. Environmental Protection Agency. 1987. *Record of Decision, Decision Summary and Responsibility Summary for Interim Final Remediation Action, Colbert Landfill Site, Colbert, WA.* September 1987.

APPENDIX A

Supplemental Groundwater Sampling and Bench Testing

APPENDIX A

INTRODUCTION

The purpose of this Appendix is to present the results of bench tests performed for Phase II treatment system design. The purposes of these bench tests are to evaluate the calcium carbonate scale formation potential during Phase II operation, evaluate the ability of phosphate and nonphosphate sequestering agents to inhibit scale formation, and correlate bench test results to observed scale accumulation during Phase I operation.

Groundwater Sampling and Analysis

Groundwater samples were collected from four monitoring wells (CD-21C1, CD-30A, CD-46C2, and CD-47C2) that were selected as representative of groundwater quality conditions in the vicinity of the proposed Phase II interception and extraction systems. Groundwater samples were collected on August 12, 1992, except that the samples used to evaluate the scale potential for Well CD-21C1 was collected June 22, 1992.

All samples were collected in general accordance with the sampling, handling, and chain-of-custody procedures described in the Phase I Quality Assurance Project Plan (Landau Associates 1989). Samples were forwarded to Landau Associates' offices in Edmonds, Washington, for compositing and bench testing. The samples were composited using a calculated flow-weighted averaged, based on the estimated contribution to total Phase II flow from each well location. Table A-1 provides the basis for the relative flow contribution estimated for each sample location used to create the composite samples.

Bench Tests

The bench test procedure used to evaluate influent scale potential was a modification of the Marble Test (American Water Works Association, Inc. 1971). The test procedure consists of the following steps:

- Place an approximate 1,000 ml water sample in a glass beaker
- Add sufficient sequestering agent to achieve the desired concentration (as appropriate)
- Add approximately 1 g calcium carbonate powder
- Aerate the sample until pH stabilizes; maintain sample temperature at about 10°C during test

- Allow sample to settle overnight
- Decant sample and filter through a 0.45 µm filter
- Place in containers for shipment to analytical laboratory or for in-house testing.

Marble Tests were performed on composite samples with different concentrations of nonphosphate (NALCO 8357) and phosphate (Betz 419) sequestering agents. Marble tests without sequestering agent addition were also performed on two composite samples, and on one sample of water from Monitoring Well CD-21C1 (for comparison to Phase I pilot test results), to evaluate scale potential without sequestering agent addition. Two untreated composite samples, and one untreated sample from Monitoring Well CD-21C1 were submitted for analyses to use as control samples for evaluating scale potential.

All samples were analyzed for total alkalinity (EPA Method 310.1), calcium (EPA Method 215.1), and hardness (Titrimetric Method; HACH 1989). Initial and final pH were also measured during bench testing.

RESULTS

Analytical results are presented in Table A-2. Harness results from Table A-2 were used to estimate groundwater scale potential, and the reduction in scale potential achieved by sequestering agent addition. Scale potential is estimated as the difference in hardness concentration between the untreated control sample and a sample subjected to the Marble Test. The analytical results show that both the phosphate (Betz 419) and nonphosphate (NALCO 8357) sequestering agents are effective in reducing or eliminating the scale potential for the composite groundwater samples.

The estimated scale potential for a composite sample without the addition of a sequestering agent is 40 ppm. The scale potential is reduced to 0 for all concentrations of Betz 419 added (3 ppm to 20 ppm). The scale potential is reduced to 0 at 8 to 10 ppm of NALCO 8357. However, a scale potential of 10-20 ppm was observed in the NALCO 8357 12-20 ppm concentration range. It is likely that the observed scale potential at 12-20 ppm of NALCO 8357 is the result of inaccuracies in the hardness test method, which is only accurate to about 10 ppm at the observed concentration.

SCALE POTENTIAL ADJUSTMENT

Although bench scale tests are useful in predicting the performance of a full scale system, an adjustment (scale up) factor is typically required to correlate bench test results to full scale facility operation. Because the Marble test creates ideal conditions for scale formation, actual scale formation for the Phase II treatment facility is anticipated to be less than that predicted by the bench tests.

Monitoring Well CD-21C1 produces groundwater of similar quality to Extraction Well CP-E1, the extraction well used for most of the Phase I treatability studies. A Marble Test was performed on a sample from Monitoring Well CD-21C1, and the analytical results from this and an untreated control sample were used to estimate an adjustment factor for full-scale operation.

The average reduction in hardness observed during Phase I treatability studies (i.e., influent minus effluent hardness concentration) was about 150 ppm (Landau Associates 1991; Vol. III, App. F). The scale potential based on bench test results for Monitoring Well CD-21C1 is 290 ppm, as shown in Table A-2. Based on these results, scale potential for the Phase II facility is anticipated to be about 50 percent (150/290 ppm) of that predicted by Marble Test results.

Using an adjustment factor of 50 percent, the scale potential for Phase II groundwater without sequestering agent addition is 20 ppm, based on bench test results. This represents a scale potential of only about 15 percent of that observed for the particular groundwater tested during Phase I treatability studies (20/150 ppm).

Although the bench test results indicate that the phosphate-based sequestering agent is 100 percent effective, and similar (although less conclusive) results were achieved for the nonphosphate-based sequestering agent, the analytical methods available to evaluate scale potential are not accurate enough to determine that scale will not form at low concentrations. As a result, a sequestering agent efficiency of 90 percent will be used for evaluating and designing additional scale control processes (i.e., acid batch cleaning); a 90 percent efficiency corresponds to a scale accumulation rate of 2 mg/L.

REFERENCES

American Water Works Associates. 1971. Water Quality and Treatment, A Handbook of Public Water Supplies. 3rd edition. McGraw-Hill. New York, NW. pp. 334-335.

HACH Company. 1989. Water Analysis Handbook, pp 292-296. HACH Company, Loveland, Colorado.

Landau Associates, Inc. 1991. Phase I Engineering Report, Colbert Landfill Remedial Design/Remedial. December 30.

TABLE A-1

ESTIMATED FLOW DISTRIBUTION FOR COMPOSITE SAMPLE PREPARATION

Sample Location	Extraction Wells Associated With Sample Locations	Estimated Phase II Flow Rate (gpm)	Relative Flow Contribution (%)
CD-21C1	CP-E1, CP-E3	150	15
CD-30A	CP-S1, CP-S3, CP-S4, CD-S5, CP-S6, CP-E2, CP-E4	345	33
CD-46C2	CP-W2, CP-W3	275	26
CD-47C2	CP-W1, CP-W4	275	26
TOTAL		1050	100

TABLE A-2

BENCH TEST ANALYTICAL RESULTS

Test No.	Source	Sequestering Agent (Type/Concentration)	Marble Test	Date Tested	pH Initial	pH Final	Hardness as $CaCO_3$ (ppm)	Total Alkalinity as $CaCO_3$ (ppm)	Calcium as $CaCO_3$ (ppm)	Scale Potential[(a)] (ppm)
1	Composite[(b)]	N/A[(c)]	N[(d)]	8/14/92	7.1	7.1	430	410	260	N/A
2	Composite[(e)]	N/A	N	8/21/92	7.2	7.2	420	400	230	N/A
3	Composite	N/A	Y[(f)]	8/14/92	7.1	8.6	390	370	230	40
4	Composite	Betz/3 ppm	Y	8/19/92	7.2	8.6	420	390	270	0
5	Composite	Betz/10 ppm	Y	8/15/92	7.2	8.5	430	410	270	0
6	Composite	Betz/20 ppm	Y	8/15/92	7.2	8.6	430	410	280	0
7	Composite	NALCO/3 ppm	Y	8/20/92	7.2	8.6	400	380	250	20
8	Composite	NALCO/5 ppm	Y	8/14/92	7.2	8.6	410	390	270	20
9	Composite	NALCO/8 ppm	Y	8/20/92	7.1	8.6	420	400	240	0
10	Composite	NALCO/10 ppm	Y	8/15/92	7.2	8.6	430	400	280	0
11	Composite	NALCO/10 ppm	Y	8/20/92	7.1	8.6	420	400	240	0
12	Composite	NALCO/12 ppm	Y	8/20/92	7.0	8.6	420	390	250	0
13	Composite	NALCO/12 ppm	Y	8/20/92	7.2	8.5	410	390	210	10
14	Composite	NALCO/15 ppm	Y	8/20/92	7.2	8.5	410	380	230	10
15	Composite	NALCO/20 ppm	Y	8/20/92	7.3	8.5	400	390	230	20
16	Composite	NALCO/50 ppm	Y	8/15/92	7.2	8.5	430	400	270	0
17	CD-21C1[(g)]	N/A	N	8/10/92	7.0	7.0	710	640	400	N/A
18	CD-21C1	N/A	Y	8/10/92	7.0	8.3	420	300	90	290

(a) Scale potential calculated as the reduction in hardness from the applicable control sample to the tested sample.
(b) Control sample for tests 3, 5, 6, 8, 10, and 16.
(c) N/A = Not applicable.
(d) N = Marble test not performed.
(e) Control sample for tests 4, 7, 9, 11, 12, 13, 14, and 15.
(f) Y = Marble test performed.
(g) Control sample for test 18.

APPENDIX B

Mass Balance Calculations

APPENDIX B
MASS BALANCE CALCULATIONS

The mass balance calculations discussed in Sections 2 and 5 present three areas of estimation which characterize treatment system operation:

- Estimation of the influent concentrations of various constituents
- Estimation of reagent usage rates for the scale control unit processes.
- Estimation of effluent concentrations of various constituents based on influent concentrations, treatment efficiency, and chemical additions from the scale control processes.

The influent flow rates analyzed were the 1,000 gpm anticipated flow and/or 1,600 gpm maximum design flow. Influent concentrations of Constituents of Concern are based on either the results of the modeling conducted for the Preliminary Extraction Well Plan (for MC and TCA), or the maximum concentrations measures during Phase I (for other Constituents of Concern). Effluent concentrations for the Constituents of Concern are set at the Performance Standards for anticipated concentrations and the Evaluation Criteria for maximum concentrations, except that effluent concentrations for DCA are set at the maximum concentration detected during Phase I (which is significantly lower than the Evaluation Criteria).

The equations used for mass balance calculations are presented below. The calculation numbers correspond to the equation numbers identified in the main body of the text.

1) **<u>Calculation of Mass Loading of Constituent In Influent</u>**

$$M_i = C_{i,m} \times Q \times \frac{1440 \times 8.34}{1{,}000{,}000}$$

or,

$$M_i = C_{i,b} \times Q \times \frac{1440 \times 8.34}{1{,}000{,}000{,}000}$$

where

M_i	=	Mass Loading Rate in Influent, lb/day
$C_{i,m}$	=	Concentration of Constituent in Influent, ppm
$C_{i,b}$	=	Concentration of Constituent in Influent, ppb
Q	=	Liquid Flow Rate, gpm
1440	=	Minutes per day
8.34	=	lb/gal (water)
1,000,000	=	ppm conversion factor
1,000,000,000	=	ppb conversion factor

2) <u>Calculation of the Mass Loading of Sequestering Agent</u>

$$M_s = C_s \times Q \times \frac{1440 \times 8.34}{1,000,000}$$

where

M_s	=	Mass Loading Rate of Sequestering Agent, lb/day
C_s	=	Sequestering Agent Dosage, ppm
Q	=	Liquid Flow Rate, gpm
1440	=	Minutes per day
8.34	=	lb/gal
1,000,000	=	gallons/million gallons

3) <u>Calculation of the Effluent Mass Loading of Constituents other than Constituents of Concern</u>

$$M_e = M_i + M_{ad}$$

where

M_e	=	Mass Loading Rate of Constituent in Effluent, lb/day
M_i	=	Mass Loading Rate of Constituent in Influent, lb/day
M_{ad}	=	Mass Loading Rate in Addition Stream, lb/day

4) **<u>Calculation of the Effluent Concentration of Constituents other than Constituents of Concern</u>**

$$C_e=\frac{M_e}{Q_e}\times\frac{1,000,000}{1440\times8.34}$$

where

C_e	=	Effluent Concentration of Constituent, ppm
M_e	=	Mass Loading Rate of Constituent in Effluent, lb/day
Q_e	=	Liquid Flow Rate, gpm
1440	=	Minutes per day
8.34	=	lb/gal
1,000,000	=	ppm conversion factor

5) **<u>Calculation of the Scale Mass Buildup Rate with No Scale Control Processes</u>**

$$M_s=(C_{h,i}-C_{h,e})\times Q\times\frac{1440\times8.34}{1,000,000}$$

where

M_s	=	Mass Scale Buildup in Air Stripping Tower, lb/day
$C_{h,i}$	=	Concentration of Hardness in Influent to Tower, ppm
	=	420 ppm
$C_{h,e}$	=	Concentration of Hardness in Effluent to Tower, ppm
	=	400 ppm
Q	=	Liquid Flow Rate, gpm
1440	=	Minutes per day
8.34	=	lb/gal
1,000,000	=	ppm conversion factor

6) Calculation of the Scale Buildup Rate with 90% Scale Control Efficiency

$$M_s = 0.10(C_{h,i} - C_{h,e}) \times Q \times \frac{1440 \times 8.34}{1,000,000}$$

$$M_T = M_s \times 365$$

where

M_s	=	Mass Scale Buildup in Air Stripping Tower, lb/day
M_T	=	Mass Scale Buildup in Air Stripping Tower, lb/year
0.05	=	Weight Fraction of Hardness Which Forms Scale at 95% Scale Control Efficiency
$C_{h,i}$	=	Concentration of Hardness in Influent to Tower, ppm
	=	420 ppm
$C_{h,e}$	=	Concentration of Hardness in Effluent to Tower, ppm
	=	400 ppm
Q	=	Liquid Flow Rate, gpm
1440	=	Minutes per day
8.34	=	lb/gal
1,000,000	=	gallons/million gallons

7) Calculation of the Mass Concentrated (100%) HCl Requirement For Annual Batch Cleaning at 90% Scale Control Efficiency After 1 Year of Operation

$$M_c = C_a \times M_T$$

where

M_c	=	Mass of Concentrated (100%) HCl Required for Batch Cleaning, lb/Batch
C_a	=	Acid Dosage for Scale Removal by Batch Cleaning lb_{acid}/lb_{scale} = 0.70
M_T	=	Mass Scale Buildup in Air Stripping Tower, lb_{scale}/year

8) **Calculation of the Mass and Volume of 35% HCl Acid Requirement For Annual Batch Cleaning at 90% Scale Control Efficiency**

$$M_{ab}=\frac{M_c}{wt}$$

$$V_{ab}=\frac{M_{ab}}{\rho_a}$$

where

V_{ab}	=	Volume of 35% HCl Required for Batch Cleaning, gal/Batch
M_{ab}	=	Mass of 35% HCl Required for Batch Cleaning, lb/Batch
M_c	=	Mass of Concentrated HCl for Batch Cleaning, lb/Batch
ρ_a	=	Density of 35% Hydrochloric Acid, lb/gal
wt	=	Weight fraction of HCl in 35% HCl solution = 0.35

9) **Calculation of the Volume of Dilution Water Required to Prepare 10% Hydrochloric Acid Solution For Batch Cleaning at 90% Scale Control Efficiency**

First, the mass of HCl per mass of 35% hydrochloric acid solution is calculated by

$$M_{hcl}=0.35M_{ab}$$

or rearranging

$$M_{ab}=\frac{M_{hcl}}{0.35}$$

where

M_{hcl}	=	Mass of HCl in 35% Hydrochloric Acid Solution Required for Batch Cleaning, lb/Batch
M_{ab}	=	Mass of 35% Hydrochloric Acid Required for Batch Cleaning, lb/Batch

Then the volume of dilution water is calculated by

$$0.1=\frac{M_{hcl}}{M_{ab}+(V_w \times \rho_w)}$$

or rearranging:

$$V_w=7.14\times\frac{M_{hcl}}{\rho_w}$$

where

V_w	=	Volume of Water Required for Batch Cleaning, gal/Batch
M_{hcl}	=	Mass of HCl in 35% Hydrochloric Acid Solution Required for Batch Cleaning, lb/Batch
ρw	=	Density of Water = 8.34 lb/gal

10) <u>Calculation of Total Volume for 10% HCl for Annual Batch Cleaning at 90% Scale Control Efficiency</u>

$$V_T = V_{ab} + V_w$$

where

V_T	=	Total volume of 35% HCl and dilution water, gal/Batch
V_{ab}	=	Volume of 35% HCl, gal/Batch
V_w	=	Volume of dilution water, gal/Batch

APPENDIX C

Computer Model Description and Design Runs

APPENDIX C

AIR STRIPPING TOWER PRELIMINARY DESIGN

INTRODUCTION

This Appendix describes the computer modelling performed for preliminary design of the Phase II air stripping system. The modelling conducted for the design of the Phase II air stripping system includes two parts:

- Analysis of Phase I treatability study results to develop mass transfer adjustment factors for model calibration
- Development of design criteria for the Phase II air stripping system based on modelled air stripping tower performance at various system configurations and operational settings.

The computer model used for this analysis is similar to that presented in the Phase I Engineering Report (Landau Associates 1991), with the calculations reorganized to allow evaluation of different tower configurations capable of achieving the effluent Performance Standards. Descriptions of the equations, development of mass transfer adjustment factors, and the procedures used for modelling of tower performance for Phase II design are presented in the following sections.

DESCRIPTION OF MODEL EQUATIONS AND SEQUENCE

The air stripping computer model utilizes the input parameters as shown in Table C-1 to calculate the output parameters shown in Table C-2. The model calculations and calculation sequence is shown following the text of this Appendix. The initial model calculations include calculation of the liquid and gas loading rates used in subsequent calculations (calculations 1 through 5). If pilot test data are being evaluated, the input parameters are those evaluated in the test run. The stripping factor of the particular compound is then calculated based on the compound's Henry's Law Constant at the liquid and gas loadings under evaluation (calculation 6).

The empirically-based equations developed by Onda (Onda 1968) are the basis for predicting air stripping tower performance utilized in the model, and include: 1) the wetted surface area of the packing (calculation 7); 2) the liquid-phase mass transfer coefficient (calculation 8); 3) the gas-phase mass transfer coefficient (calculation 9); and 4) the overall liquid-phase mass transfer coefficient and the adjusted overall liquid-phase mass transfer coefficient (calculation 10). The adjusted overall mass transfer coefficient is the overall mass transfer coefficient modified by the adjustment factor described in the next subsequent section of this Appendix.

The number of transfer units required to achieve the effluent Performance Standard for a given Constituent of Concern is then calculated (calculation 11), and the height of a transfer unit is calculated based on the (adjusted) overall liquid-phase mass transfer coefficient (calculation 12). The number of transfer units is then multiplied by the height of a transfer unit to determine the required packing height of the system (calculation 13), based on the influent and effluent concentrations and loading conditions being evaluated. The required packing volume is then calculated based on the required packing height and the diameter of the tower (calculation 14).

The system energy requirements are estimated as the sum of the blower and pump horsepower requirements at the tower operating conditions and required packing height. The packing pressure drop is estimated (calculation 15) based on the incremental pressure drop per foot of packing (from the packing manufacturer's literature) and the required packing height. The blower horsepower is then calculated (calculation 16) based on the pressure drop experienced by the air, and the air flow rate under analysis. The pump horsepower is estimated (calculation 17) based on the lift required to pump the groundwater flow rate to the top of the required packing height. The total system horsepower is calculated (calculation 18) by summing the blower and pump horsepowers.

ADJUSTMENT FACTORS

The adjustment factor represents the factor that must be applied to the model-predicted overall liquid-phase mass transfer coefficient to calibrate the model to observed performance during pilot test runs. The initial step in determining the adjustment factor is calculating the actual number of transfer units achieved by the pilot test run (calculated 19), based on the actual influent and effluent concentrations and the gas and liquid loading rates used in the pilot run. The actual height of a transfer unit achieved in the pilot test is then calculated (calculation 20) based the actual height of the tower used in the pilot test. The actual measured overall liquid-phase mass transfer coefficient is then calculated (calculation 21) based on the liquid loading rate and actual height of a transfer unit. The adjustment factor is then calculated based on the ratio of the predicted and actual overall liquid-phase mass transfer coefficient (calculation 22).

Table C-3 presents the mass transfer adjustment factors developed for the 16 Phase I Treatability Study pilot runs, (based on calculations 19 through 22 described above), adjustment factor summary data, and the selected Phase II design adjustment factor. As shown in Table C-3, the Phase II design adjustment factor was selected at, or near, the maximum adjustment factor calculated for the pilot test runs. Table C-4 presents an example analysis of the pilot test data and calculation of adjustment factors for each of the six Constituents of Concern, based on the results from Phase I Treatability Study Pilot Test Run Number 1 (Landau Associates 1991).

PRELIMINARY PHASE II DESIGN PROCESS

The Phase II stripping tower preliminary design analysis was conducted by varying the stripping tower diameter and air-to-water ratio operational settings, and calculating the packing height required to achieve the effluent Performance Standards. The preliminary design analyses conducted for the Phase II air stripping system are summarized in Table C-5. Tower configurations and minimum operating conditions that are predicted to achieve effluent Performance Standards within a preliminary target packing height of 50 ft are highlighted in Table C-5. The design analyses were conducted for anticipated and maximum groundwater flow rates and influent concentrations, except that the combined maximum flow rate and influent concentration was not modelled (because of its low probability of occurrence). For each grouping of influent parameters, the tower diameter was varied between 8 and 12 ft, and the air to water ratios were varied between 60:1 and 120:1 (volume:volume).

Tables C-6 through C-22 present input and output data for the model runs conducted for the preliminary Phase II stripping tower design analysis. The design runs are grouped as follows: 1) Tables C-6 through C-15 present the design analysis for the anticipated groundwater flow rate (1,000 gpm) and the anticipated methylene chloride concentration (500 ppb); 2) Tables C-16 through C-22 present the design analysis for the anticipated groundwater flow rate (1,000 gpm) and the maximum methylene chloride concentration (1,300 ppb); and 3) Tables C-23 through C-28 present the design analysis for the maximum groundwater flow rate (1,600 gpm) and the anticipated methylene chloride concentration (500 ppb).

Design runs shown in Tables C-10, C-14, C-18, and C-23 present the modelling results for all six Constituents of Concern. The other design runs present results for methylene chloride only. The four complete design runs (for all Constituents of Concern) show that the required packing height to achieve effluent Performance Standards for constituents (other than methylene chloride) are less than the required packing height for methylene chloride, demonstrating that methylene chloride is the controlling parameter for stripping tower design.

AIR STRIPPING MODEL CALCULATIONS

Calculation 1: Liquid Volumetric Loading Rate

$$L_{vol}=\frac{4L}{\pi D^2}$$

where

L_{vol}	=	Liquid volumetric loading rate, gpm/ft^2
L	=	Liquid flow rate, gpm
D	=	Tower diameter, ft

Calculation 2: Liquid Mass Loading

$$L_{mas}=L_{vol}\frac{\rho_l}{(7.48)(60)}$$

where

L_{mas}	=	Liquid mass loading rate, lb$_m$/sec-ft^2
L_{vol}	=	Liquid volumetric loading rate, gpm/ft^2
ρl	=	Liquid Density, lb$_m$/ft^3

Calculation 3: Gas Volumetric Loading

$$G_{vol}=A\frac{L_{vol}}{7.48}$$

where

G_{vol}	=	Gas Volumetric Loading Rate, cfm/ft^2
A	=	Volumetric air to water ratio, dimensionless

Calculation 4: Gas Flow Rate

$$G = G_{vol} \frac{\pi D^2}{4}$$

where

G = Gas Flow Rate, cfm

Calculation 5: Gas Mass Loading Rate

$$G_{mas} = G_{vol} \frac{\rho_g}{(60)}$$

where

G_{mas} = Gas mass loading rate, $lb_m/sec\text{-}ft^2$

ρ_g = Gas Density, lb_m/ft^3

Calculation 6: Stripping Factor

$$R_i = H_i \frac{G_{mas}}{29} \frac{18}{L_{mas}}$$

where

R_i = Stripping Factor for compound i, dimensionless

H_i = Henry's constant for compound i, atm

29 = Molecular weight of air lb/lb_{mole}

18 = Molecular weight of water, lb/lb_{mole}

Calculation 7: Packing Wetted Surface Area

Calculation of the wetted surface area of the packing based upon packing material of construction, Reynolds, Froude and Weber numbers.

$$a_w = a_t[1 - e^{\left(-1.45\left(\frac{\sigma_c}{\sigma}\right)^{0.75} N_{Re}^{0.1} N_{Fr}^{-0.05} N_{We}^{0.2}\right)}]$$

where

$$N_{Re} = \frac{L_{mas}}{a_t \mu_l}$$

$$N_{Fr} = \frac{L_{mas}^2 a_t}{\rho_l^2 g}$$

$$N_{We} = \frac{L_{mas}^2}{\rho_w \sigma a_t}$$

where

a_w	=	Unit wetted packing surface area, ft^2/ft^3
a_t	=	Unit packing surface area, ft^2/ft^3
σ_c	=	Critical surface tension of packing material, lb/sec^2
σ	=	Liquid surface tension, lb/sec^2
μ_e	=	Liquid viscosity, lb_m/ft-sec
g	=	Gravitational acceleration = 32 ft/s^2

Calculation 8: Liquid Phase Mass Transfer Coefficient

$$k_l = 0.0051\left(\frac{L_{mas}}{a_w \mu_l}\right)^{2/3}\left(\frac{\mu_l}{\rho_l D_{il}}\right)^{-1/2}(a_t D_p)^{0.4}\left(\frac{\rho_l}{\mu_l g}\right)^{-1/3}(3600)$$

where

k_l	=	Liquid phase mass transfer coefficient, ft/hr
D_{il}	=	Diffusivity of compound i in water, ft^2/sec
D_p	=	Packing Diameter, in

Calculation 9: Gas-Phase Mass Transfer Coefficient

$$k_g = C_1 \beta \gamma \psi \xi \times 3600$$

where

$$\beta = \left(a_t \frac{D_p}{12}\right)^{-2}$$

$$\gamma = \left(\frac{G_{mas}}{a_t \mu_g}\right)^{0.7}$$

$$\psi = \left(\frac{\mu_g}{\rho_g D_{ig}}\right)^{1/3}$$

$$\xi = a_t D_{ig}$$

where

k_g = Gas phase mass transfer coefficient, ft/hr

μ_g = Gas viscosity, lb_m/ft-sec

ρ_g = Density of air, lb_m/ft^3

C_1 = Constant
= 5.23 for packings larger than 1/2-inch diameter
= 2.00 for packings smaller than 1/2-inch diameter

Calculation 10: Overall Liquid Phase Mass Transfer Coefficient

$$K_l a = \frac{1}{\frac{1}{k_l a_w} + \frac{1}{H_{ci} k_g a_w}}$$

$$K_l a' = K_l a \left(1 - \frac{AF_i}{100}\right)$$

where

$K_l a$ = Overall liquid phase mass transfer coefficient, 1/hr

H_{ci} = Dimensionless Henry's constant for compound i, atm, 0.2194 x H_i

$K_l a'$ = Overall liquid phase mass transfer coefficient modified based upon treatability study data, 1/hr

AF_i = Adjustment factor for treatability study data, percent

Calculation 11: Number of Transfer Units Required

Calculates the required number of packing transfer units required to achieve the effluent Performance Standard concentration.

$$NTU=\frac{R_i}{R_i-1}\ln\left[\frac{\frac{C_{i,i}}{C_{i,f}}(R_i-1)+1}{R_i}\right]$$

where

NTU	=	Number of Transfer Units, dimensionless
$C_{i,i}$	=	Influent concentration of compound i, ppb
$C_{i,f}$	=	Effluent concentration of compound i, ppb

Calculation 12: Height of a Transfer Unit

$$HTU=\frac{L_{mas}}{K_l a \rho_w 3600}$$

where

HTU	=	Height of Transfer Unit, ft
$K_l a$	=	Overall mass transfer unit ($K_l a'$, when appropriate),

Calculation 13: Required Packing Height

$$h_t=HTUxNTU$$

where

h_t = Required packing height to achieve effluent performance standards, ft

Calculation 14: Required Packing Volume

$$PV=(h_t)\pi\frac{D^2}{4}$$

where

PV = Required packing volume to achieve effluent performance standards, ft^3

Calculation 15: Total Packing Pressure Drop

$$PT = h_t \times DP$$

where

PT	=	Total Pressure Drop Through Packing, ft H_2O
DP	=	Pressure Drop Through Packing, in ft H_2O/ft packing

Calculation 16: Blower Horsepower

$$BHP = \frac{LF \times G \times PT}{e_b} \times 0.00157$$

where

BHP	=	Required blower horsepower, horsepower
LF	=	Loss factor multiplier for losses other than packing = 1.1 (assumed)
e_b	=	blower efficiency factor = 0.8 (assumed)

Calculation 17: Groundwater Pump Horsepower to Lift to Top of Packing

$$PHP = \frac{LF \times L \times ht}{e_p \times 3960}$$

where

BHP	=	Required blower horsepower, horsepower
LF	=	Loss factor multiplier for other losses
	=	1.1
e_p	=	pump efficiency factor
	=	0.8
L	=	Liquid flow rate, gpm
h_t	=	Required packing height to achieve Performance Standards, ft

Calculation 18: Total Horsepower

$$THP = PHP + BHP$$

where

THP = Total system horsepower, horsepower

Calculation 19: Actual Number of Transfer Units From Pilot Test Data

Calculates the actual number of packing transfer units achieved based on actual influent and effluent concentrations from pilot test data. Note that this calculated value is not shown as an output parameter in Table D-2.

$$NTU_a = \frac{R_i}{R_i - 1} \ln\left[\frac{\frac{C_{a,i}}{C_{a,f}}(R_i - 1) + 1}{R_i}\right]$$

where

NTU_a = Actual number of transfer units, dimensionless

$C_{a,i}$ = Actual influent concentration of compound, ppb

$C_{a,f}$ = Actual effluent concentration of compound, ppb

Calculation 20: Actual Height of Transfer Unit From Pilot Test Data

Calculates the actual height of a packing transfer unit based on the achieved number of transfer units and the tower height from pilot test data. Note that this calculated value is not shown as an output parameter in Table D-2.

$$HTU_a = \frac{h_a}{NTU_a}$$

where

HTU_a = Actual height of transfer unit, ft

h_a = Actual tower height from pilot test, ft

Calculation 21: Actual Overall Liquid Phase Mass Transfer Coefficient from Pilot Test Data

Calculates the actual overall liquid phase mass transfer coefficient based on the achieved height of a transfer unit from pilot test data.

$$K_l a,a = \frac{L_{mas}}{HTU_a \times \rho_l} \times 3600$$

where

$K_l a,a$ = Actual overall liquid phase mass transfer coefficient, 1/hr

Calculation 22: Actual Adjustment Factor for Overall Liquid Phase Mass Transfer Coefficient from Pilot Test Data

$$AF_a = -\left(\frac{K_l a,a}{K_l a} - 1\right) \times 100$$

where

AF_a = Actual adjustment factor based on pilot test data, percent

TABLE C-1

MODEL INPUT PARAMETERS

Variable	Definition
L	Water flow rate, gpm
D	Tower diameter, feet
A	Volumetric Air To Water Ratio, dimensionless
T	Liquid temperature, C
ρl	Liquid density, lb/ft^3
l	Liquid viscosity, lb/ft-sec
σ	Liquid surface tension, lb/sec^2
ρg	Gas density, lb/ft^3
g	Gas viscosity, lb/ft-sec
NCON	Compound name
AF_i	Adjustment factor, percent
$D_{i\ell}$	Diffusivity of compound i in water, ft^2/sec
D_{ig}	Diffusivity of compound i in air, ft^2/sec
$C_{i,i}$	Influent concentration, ug/L
$C_{i,f}$	Final required effluent concentration, ug/L
H_i	Henry's constant for compound i, atm
NP	Packing name
D_p	Packing diameter, in
a_w	Packing specific surface area, ft^2/ft^3
σ_c	Critical surface tension of packing material, $dyne/cm^2$
DP	Pressure drop through packing, in. H_2O/ft packing
h_a	Actual height of packing from pilot test, ft
$C_{a,i}$	Actual influent concentration from pilot test, ug/L
$C_{a,f}$	Actual effluent concentration from pilot test, ug/L

TABLE C-2

MODEL OUTPUT PARAMETERS

Variable	Description
L_{vol}	Liquid volumetric loading rate, gpm/ft^2
L_{mas}	Liquid mass loading rate, lb$_m$/sec-ft^2
G_{vol}	Gas volumetric loading rate, cfm/ft^2
G	Gas flow rate, cfm
G_{mas}	Gas mass loading rate, lb$_m$/sec-ft^2
R	Stripping factor
a_w	Specific wetted surface area of packing, ft^2/ft^3
k_l	Liquid phase mass transfer coefficient, ft/hr
k_g	Gas phase mass transfer coefficient, ft/hr
Kla	Overall mass transfer coefficient, 1/hr
Kla'	Overall mass transfer coefficient with adjustment factor, 1/hr
NTU	Number of transfer units, transfer units
HTU	Height of transfer unit, ft
h_t	Required packing depth to achieve required effluent concentration, ft
PV	Required packing volume to achieve required effluent concentration, ft^3
DT	Total pressure drop through packing, in. H_2O
BHP	Blower energy requirement, horsepower
PHP	Pumping energy requirement, horsepower
THP	Total energy requirement, horsepower
$Kl_{a,a}$	Actual packing depth to achieve required effluent concentration, ft
AF_a	Actual adjustment factor calculated from pilot test data, percent

TABLE C-3
COLBERT LANDFILL RD/RA
SUMMARY OF MASS TRANSFER COEFFICIENT
(KLA) ADJUSTMENT FACTORS
BASED ON PILOT TEST DATA

	Adjustment Factor (%)					
	MECL	1,1,1-TCA	1,1-DCA	1,1-DCE	TCE	PCE
Pilot Run Number						
1	18	17	27	20	27	38
2	9	18	30	23	32	38
3	12	25	30	24	31	37
4	24	25	32	34	43	36
5	24	27	39	31	41	38
6	20	25	37	31	41	40
7	21	26	35	29	42	36
8	14	16	31	29	40	45
9	21	13	26	19	25	35
10	19	9	25	27	32	40
11	26	4	21	29	35	51
12	22	6	33	31	35	43
13	23	6	36	16	27	42
14	14	-5	32	23	32	50
15	29	-7	26	40	32	48
16	27	6	19	29	33	43
Adjustment Factor Summary						
Average All Runs	20	13	30	27	34	41
Average for 3.5-Inch Packing	18	22	33	28	37	39
Average for 2-Inch Packing	23	4	27	27	31	44
Maximum	29	27	39	40	43	51
Minimum	9	-7	19	16	25	35
Phase II Design						
Adjustment Factor	30	30	40	40	45	50

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TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

INPUT PARAMETERS (GENERAL)

Variables Analyzed in This Run

Water Flow Rate (gpm)	203
Tower Diameter (ft)	3.5
Air To Water Ratio (Dimensionless)	74.2

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

INPUT PARAMETERS (MC)

Contaminant Properties

Contaminant Name	Methylene Chloride
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	3100
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

CALCULATED PARAMETERS (MC)

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	21.11
Liquid Mass Loading Rate (lb/sec-ft2)	2.94
Gas Volumetric Loading Rate (cfm/ft2)	209.41
Gas Flow Rate (cfm)	2013.72
Gas Mass Loading Rate (lb/sec-ft2)	0.26246
Stripping Factor - R (dimensionless)	3.55

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20.48
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3.00
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	65.05
Overall Mass Transfer Coefficient - kla (1/hr)	31.84
Number of Transfer Units - NTU (transfer units)	9.45
Height of Transfer Unit - HTU (ft)	5.32
Required Packing Depth (ft)	50.28
Required Packing Volume (ft3)	483.53

PILOT TEST DATA ANALYSIS (MC)

Pilot Test Parameters

Actual Influent Concentration (ug/l)	3100
Actual Effluent Concentration (ug/l)	22
Actual Packing Depth (ft)	41.5

Calculated Pilot Test Parameters

Actual NTU (Transfer Units)	6.43
Actual HTU (ft)	6.45
Actual Kla (1/hr)	26.24
Kla Adjustment Factor (percent)	17.6

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

INPUT PARAMETERS (TCA)

Contaminant Properties

Contaminant Name	1,1,1-TCA
Liquid Phase Diffusivity (ft2/sec)	0.0000000072
Gas Phase Diffusivity (ft2/sec)	0.0000834
Influent Concentration (ug/l)	2600
Required Effluent Concentration (ug/l)	200
Henrys Law Constant (atm)	135

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727

CALCULATED PARAMETERS (TCA)

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	21.11
Liquid Mass Loading Rate (lb/sec-ft2)	2.94
Gas Volumetric Loading Rate (cfm/ft2)	209.41
Gas Flow Rate (cfm)	2013.72
Gas Mass Loading Rate (lb/sec-ft2)	0.26246
Stripping Factor - R (dimensionless)	7.49

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20.48
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2.60
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	55.05
Overall Mass Transfer Coefficient - kla (1/hr)	36.66
Number of Transfer Units - NTU (transfer units)	2.81
Height of Transfer Unit - HTU (ft)	4.62
Required Packing Depth (ft)	12.97
Required Packing Volume (ft3)	124.72

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

PILOT TEST DATA ANALYSIS (TCA)

Pilot Test Parameters

Actual Influent Concentration (ug/l)	2600
Actual Effluent Concentration (ug/l)	3.53
Actual Packing Depth (ft)	41.5

Calculated Pilot Test Parameters

Actual NTU (Transfer Units)	7.45
Actual HTU (ft)	5.57
Actual Kla (1/hr)	30.41
Kla Adjustment Factor (percent)	17.0

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

INPUT PARAMETERS (DCA)

Contaminant Properties

Contaminant Name	1,1-DCA
Liquid Phase Diffusivity (ft2/sec)	0.0000000081
Gas Phase Diffusivity (ft2/sec)	0.0000933
Influent Concentration (ug/l)	54.5
Required Effluent Concentration (ug/l)	4050
Henrys Law Constant (atm)	139

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727

CALCULATED PARAMETERS (DCA)

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	21.11
Liquid Mass Loading Rate (lb/sec-ft2)	2.94
Gas Volumetric Loading Rate (cfm/ft2)	209.41
Gas Flow Rate (cfm)	2013.72
Gas Mass Loading Rate (lb/sec-ft2)	0.26246
Stripping Factor - R (dimensionless)	7.71

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20.48
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2.75
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	59.35
Overall Mass Transfer Coefficient - kla (1/hr)	39.36
Number of Transfer Units - NTU (transfer units)	-2.25
Height of Transfer Unit - HTU (ft)	4.30
Required Packing Depth (ft)	-9.67
Required Packing Volume (ft3)	-92.99

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

PILOT TEST DATA ANALYSIS (DCA)

Pilot Test Parameters

Actual Influent Concentration (ug/l)	54.5
Actual Effluent Concentration (ug/l)	2
Actual Packing Depth (ft)	21.5

Calculated Pilot Test Parameters

Actual NTU (Transfer Units)	3.64
Actual HTU (ft)	5.90
Actual Kla (1/hr)	28.70
Kla Adjustment Factor (percent)	27.1

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

INPUT PARAMETERS (DCE)

Contaminant Properties

Contaminant Name	1,1-DCE
Liquid Phase Diffusivity (ft2/sec)	0.0000000085
Gas Phase Diffusivity (ft2/sec)	0.000098
Influent Concentration (ug/l)	350
Required Effluent Concentration (ug/l)	7
Henrys Law Constant (atm)	461

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727

CALCULATED PARAMETERS (DCE)

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	21.11
Liquid Mass Loading Rate (lb/sec-ft2)	2.94
Gas Volumetric Loading Rate (cfm/ft2)	209.41
Gas Flow Rate (cfm)	2013.72
Gas Mass Loading Rate (lb/sec-ft2)	0.26246
Stripping Factor - R (dimensionless)	25.59

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20.48
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2.82
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	61.34
Overall Mass Transfer Coefficient - kla (1/hr)	51.20
Number of Transfer Units - NTU (transfer units)	4.03
Height of Transfer Unit - HTU (ft)	3.31
Required Packing Depth (ft)	13.33
Required Packing Volume (ft3)	128.18

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

PILOT TEST DATA ANALYSIS (DCE)

Pilot Test Parameters

Actual Influent Concentration (ug/l)	350
Actual Effluent Concentration (ug/l)	2.2
Actual Packing Depth (ft)	21.5

Calculated Pilot Test Parameters

Actual NTU (Transfer Units)	5.23
Actual HTU (ft)	4.11
Actual Kla (1/hr)	41.23
Kla Adjustment Factor (percent)	19.5

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

INPUT PARAMETERS (TCE)

Contaminant Properties

Contaminant Name	TCE
Liquid Phase Diffusivity (ft2/sec)	0.0000000075
Gas Phase Diffusivity (ft2/sec)	0.0000853
Influent Concentration (ug/l)	59.7
Required Effluent Concentration (ug/l)	5
Henrys Law Constant (atm)	247

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727

CALCULATED PARAMETERS (TCE)

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	21.11
Liquid Mass Loading Rate (lb/sec-ft2)	2.94
Gas Volumetric Loading Rate (cfm/ft2)	209.41
Gas Flow Rate (cfm)	2013.72
Gas Mass Loading Rate (lb/sec-ft2)	0.26246
Stripping Factor - R (dimensionless)	13.71

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20.48
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2.66
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	55.89
Overall Mass Transfer Coefficient - kla (1/hr)	43.58
Number of Transfer Units - NTU (transfer units)	2.60
Height of Transfer Unit - HTU (ft)	3.89
Required Packing Depth (ft)	10.10
Required Packing Volume (ft3)	97.16

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

PILOT TEST DATA ANALYSIS (TCE)

Pilot Test Parameters

Actual Influent Concentration (ug/l)	59.7
Actual Effluent Concentration (ug/l)	1.3
Actual Packing Depth (ft)	21.5

Calculated Pilot Test Parameters

Actual NTU (Transfer Units)	4.05
Actual HTU (ft)	5.31
Actual Kla (1/hr)	31.88
Kla Adjustment Factor (percent)	26.8

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

INPUT PARAMETERS (PCE)

Contaminant Properties

Contaminant Name	PCE
Liquid Phase Diffusivity (ft2/sec)	0.0000000068
Gas Phase Diffusivity (ft2/sec)	0.0000768
Influent Concentration (ug/l)	2.13
Required Effluent Concentration (ug/l)	0.7
Henrys Law Constant (atm)	647

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727

CALCULATED PARAMETERS (PCE)

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	21.11
Liquid Mass Loading Rate (lb/sec-ft2)	2.94
Gas Volumetric Loading Rate (cfm/ft2)	209.41
Gas Flow Rate (cfm)	2013.72
Gas Mass Loading Rate (lb/sec-ft2)	0.26246
Stripping Factor - R (dimensionless)	35.91

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20.48
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2.53
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	52.09
Overall Mass Transfer Coefficient - kla (1/hr)	47.17
Number of Transfer Units - NTU (transfer units)	1.13
Height of Transfer Unit - HTU (ft)	3.59
Required Packing Depth (ft)	4.04
Required Packing Volume (ft3)	38.84

TABLE C-4
AIR STRIPPING TOWER ANALYSIS
COLBERT LANDFILL RD\RA
PILOT RUN 1

PILOT TEST DATA ANALYSIS (PCE)

Pilot Test Parameters

Actual Influent Concentration (ug/l)	2.13
Actual Effluent Concentration (ug/l)	0.3
Actual Packing Depth (ft)	11.5

Calculated Pilot Test Parameters

Actual NTU (Transfer Units)	1.99
Actual HTU (ft)	5.78
Actual Kla (1/hr)	29.32
Kla Adjustment Factor (percent)	37.8

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TABLE C-5

SUMMARY OF DESIGN ANALYSES[(a)(b)]

Design Run	Tower Diameter (ft)	Air/Water Ratio (Vol/Vol)	Required Packing Height (ft)	Packing Volume (ft^3)	Energy Requirements (HP)
Series 1—Anticipated Flow (1000 gpm), Anticipated MC Concentration (625 ppb)					
1	8	60	63	3200	31
2	8	80	52	2600	34
3	8	100	46	2300	43
4	10	60	60	4700	26
5	10	80	49	3800	23
6	10	100	43	3400	23
7	12	60	58	6500	25
8	12	80	47	5300	21
9	12	100	41	4600	20
Series 2—Anticipated Flow (1,000 gpm), Maximum MC Concentration (1300 ppb)					
10	8	100	52	2600	49
11	8	120	48	2400	64
12	10	80	56	4400	25
13	10	100	49	3800	26
14	12	80	53	6000	24
15	12	100	47	5300	22
Series 3—Maximum Flow (1600 gpm), Anticipated MC Concentration (625 ppb)					
16	8	100	49	2500	236
17	8	120	45	2300	370
18	10	80	52	4100	55
19	10	100	46	3600	74
20	10	120	42	3300	98
21	12	80	50	5600	38
22	12	100	44	4900	40

(a) Minimum successful design run for each tower diameter to achieve MC Performance Standard with a packing height <50 ft is shaded.

(b) Highlighted rows are design runs which achieved required removal in target packing height of 50 ft.

TABLE C-6
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 1 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	60

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.035

TABLE C-6
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 1 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	3
Gas Volumetric Loading Rate (cfm/ft2)	160
Gas Flow Rate (cfm)	8021
Gas Mass Loading Rate (lb/sec-ft2)	0.20
Stripping Factor - R (dimensionless)	3

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	54
Overall Mass Transfer Coefficient - kla (1/hr)	28
Overall Coefficient w/Adjust Factor - kla' (1/hr)	20
Number of Transfer Units - NTU (transfer units)	7.8
Height of Transfer Unit - HTU (ft)	8.1
Required Packing Depth (ft)	63
Packing Volume (ft3)	3189

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	2.22
Blower Power (hp)	9
Pump Power (hp)	22
Total Power Requirement (hp)	31

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TABLE C-7
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 2 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	80

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.058

TABLE C-7
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 2 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	3
Gas Volumetric Loading Rate (cfm/ft2)	213
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	4

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	66
Overall Mass Transfer Coefficient - kla (1/hr)	31
Overall Coefficient w/Adjust Factor - kla' (1/hr)	22
Number of Transfer Units - NTU (transfer units)	7.1
Height of Transfer Unit - HTU (ft)	7.3
Required Packing Depth (ft)	52
Packing Volume (ft3)	2608

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	3.01
Blower Power (hp)	16
Pump Power (hp)	18
Total Power Requirement (hp)	34

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TABLE C-8
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 3 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed In This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.09

TABLE C-8
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 3 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	3
Gas Volumetric Loading Rate (cfm/ft2)	266
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.33
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	77
Overall Mass Transfer Coefficient - kla (1/hr)	33
Overall Coefficient w/Adjust Factor - kla' (1/hr)	23
Number of Transfer Units - NTU (transfer units)	6.7
Height of Transfer Unit - HTU (ft)	6.8
Required Packing Depth (ft)	46
Packing Volume (ft3)	2299

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	4.12
Blower Power (hp)	27
Pump Power (hp)	16
Total Power Requirement (hp)	43

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TABLE C-9
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 4 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	60

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-9
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 4 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	102
Gas Flow Rate (cfm)	8021
Gas Mass Loading Rate (lb/sec-ft2)	0.13
Stripping Factor - R (dimensionless)	3

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	39
Overall Mass Transfer Coefficient - kla (1/hr)	19
Overall Coefficient w/Adjust Factor - kla' (1/hr)	13
Number of Transfer Units - NTU (transfer units)	7.8
Height of Transfer Unit - HTU (ft)	7.7
Required Packing Depth (ft)	60
Packing Volume (ft3)	4717

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.20
Blower Power (hp)	5
Pump Power (hp)	21
Total Power Requirement (hp)	26

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TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (GENERAL)

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	80

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

INPUT PARAMETERS (METHYLENE CHLORIDE)

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.024

TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	4

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	48
Overall Mass Transfer Coefficient - kla (1/hr)	21
Overall Coefficient w/Adjust Factor - kla' (1/hr)	15
Number of Transfer Units - NTU (transfer units)	7.1
Height of Transfer Unit - HTU (ft)	6.9
Required Packing Depth (ft)	49
Packing Volume (ft3)	3838

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.17
Blower Power (hp)	6
Pump Power (hp)	17
Total Power Requirement (hp)	23

TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1,1-TCA)

Contaminant Properties

Contaminant Name	1,1,1-TCA
Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000072
Gas Phase Diffusivity (ft2/sec)	0.0000834
Influent Concentration (ug/l)	1100
Required Effluent Concentration (ug/l)	200
Henrys Law Constant (atm)	135

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.024

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	8

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	41
Overall Mass Transfer Coefficient - kla (1/hr)	25
Overall Coefficient w/Adjust Factor - kla' (1/hr)	17
Number of Transfer Units - NTU (transfer units)	1.8
Height of Transfer Unit - HTU (ft)	6.0
Required Packing Depth (ft)	11
Packing Volume (ft3)	852

TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1-DCA)

Contaminant Properties

Contaminant Name	1,1-DCA
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000081
Gas Phase Diffusivity (ft2/sec)	0.0000933
Influent Concentration (ug/l)	180
Required Effluent Concentration (ug/l)	4050
Henrys Law Constant (atm)	139

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.024

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	8

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	44
Overall Mass Transfer Coefficient - kla (1/hr)	26
Overall Coefficient w/Adjust Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	-2.1
Height of Transfer Unit - HTU (ft)	6.5
Required Packing Depth (ft)	-13
Packing Volume (ft3)	-1059

TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1-DCE)

Contaminant Properties

Contaminant Name	1,1-DCE
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000085
Gas Phase Diffusivity (ft2/sec)	0.000098
Influent Concentration (ug/l)	300
Required Effluent Concentration (ug/l)	7
Henrys Law Constant (atm)	461

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.024

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	28

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	45
Overall Mass Transfer Coefficient - kla (1/hr)	35
Overall Coefficient w/Adjust Factor - kla' (1/hr)	21
Number of Transfer Units - NTU (transfer units)	3.9
Height of Transfer Unit - HTU (ft)	4.9
Required Packing Depth (ft)	19
Packing Volume (ft3)	1491

TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (TCE)

Contaminant Properties

Contaminant Name	TCE
Adjustment Factor (percent)	45
Liquid Phase Diffusivity (ft2/sec)	0.0000000075
Gas Phase Diffusivity (ft2/sec)	0.0000853
Influent Concentration (ug/l)	580
Required Effluent Concentration (ug/l)	5
Henrys Law Constant (atm)	247

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.024

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	15

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	41
Overall Mass Transfer Coefficient - kla (1/hr)	29
Overall Coefficient w/Adjust Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	5.0
Height of Transfer Unit - HTU (ft)	6.3
Required Packing Depth (ft)	32
Packing Volume (ft3)	2498

TABLE C-10
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 5 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (PCE)

Contaminant Properties

Contaminant Name	PCE
Adjustment Factor (percent)	50
Liquid Phase Diffusivity (ft2/sec)	0.0000000068
Gas Phase Diffusivity (ft2/sec)	0.0000768
Influent Concentration (ug/l)	2.9
Required Effluent Concentration (ug/l)	0.7
Henrys Law Constant (atm)	647

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.024

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	39

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	39
Overall Mass Transfer Coefficient - kla (1/hr)	32
Overall Coefficient w/Safety Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	1.4
Height of Transfer Unit - HTU (ft)	6.4
Required Packing Depth (ft)	9
Packing Volume (ft3)	722

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TABLE C-11
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 6 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	100

Phsyical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.027

TABLE C-11
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 6 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	2
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	56
Overall Mass Transfer Coefficient - kla (1/hr)	23
Overall Coefficient w/Adjust Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	6.7
Height of Transfer Unit - HTU (ft)	6.4
Required Packing Depth (ft)	43
Packing Volume (ft3)	3371

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.16
Blower Power (hp)	8
Pump Power (hp)	15
Total Power Requirement (hp)	23

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TABLE C-12
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 7 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	60

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-12
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 7 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1
Gas Volumetric Loading Rate (cfm/ft2)	71
Gas Flow Rate (cfm)	8021
Gas Mass Loading Rate (lb/sec-ft2)	0.09
Stripping Factor - R (dimensionless)	3

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	30
Overall Mass Transfer Coefficient - kla (1/hr)	14
Overall Coefficient w/Adjust Factor - kla' (1/hr)	10
Number of Transfer Units - NTU (transfer units)	7.8
Height of Transfer Unit - HTU (ft)	7.4
Required Packing Depth (ft)	58
Packing Volume (ft3)	6532

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.16
Blower Power (hp)	5
Pump Power (hp)	20
Total Power Requirement (hp)	25

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TABLE C-13
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 8 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed In This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	80

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-13
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 8 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates	
Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	95
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.12
Stripping Factor - R (dimensionless)	4
Mass Transfer Parameters	
Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	37
Overall Mass Transfer Coefficient - kla (1/hr)	15
Overall Coefficient w/Adjust Factor - kla' (1/hr)	11
Number of Transfer Units - NTU (transfer units)	7.1
Height of Transfer Unit - HTU (ft)	6.6
Required Packing Depth (ft)	47
Packing Volume (ft3)	5294
Energy Factors	
Total Air Pressure Drop in Packing (inches H2O)	0.94
Blower Power (hp)	5
Pump Power (hp)	16
Total Power Requirement (hp)	21

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TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (GENERAL)

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

INPUT PARAMETERS (METHYLENE CHLORIDE)

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	4.8

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	44
Overall Mass Transfer Coefficient - kla (1/hr)	17
Overall Coefficient w/Adjust Factor - kla' (1/hr)	12
Number of Transfer Units - NTU (transfer units)	6.7
Height of Transfer Unit - HTU (ft)	6.1
Required Packing Depth (ft)	41
Packing Volume (ft3)	4635

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	0.82
Blower Power (hp)	5
Pump Power (hp)	14
Total Power Requirement (hp)	20

TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1,1-TCA)

Contaminant Properties

Contaminant Name	1,1,1-TCA
Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000072
Gas Phase Diffusivity (ft2/sec)	0.0000834
Influent Concentration (ug/l)	1100
Required Effluent Concentration (ug/l)	200
Henrys Law Constant (atm)	135

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	10

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	37
Overall Mass Transfer Coefficient - kla (1/hr)	19
Overall Coefficient w/Adjust Factor - kla' (1/hr)	13
Number of Transfer Units - NTU (transfer units)	1.8
Height of Transfer Unit - HTU (ft)	5.3
Required Packing Depth (ft)	10
Packing Volume (ft3)	1086

TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1,-DCA)

Contaminant Properties

Contaminant Name	1,1-DCA
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000081
Gas Phase Diffusivity (ft2/sec)	0.0000933
Influent Concentration (ug/l)	180
Required Effluent Concentration (ug/l)	4050
Henrys Law Constant (atm)	139

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	10

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	40
Overall Mass Transfer Coefficient - kla (1/hr)	20
Overall Coefficient w/Adjust Factor - kla' (1/hr)	12
Number of Transfer Units - NTU (transfer units)	-2.2
Height of Transfer Unit - HTU (ft)	5.8
Required Packing Depth (ft)	-13
Packing Volume (ft3)	-1447

TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1-DCE)

Contaminant Properties

Contaminant Name	1,1-DCE
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000085
Gas Phase Diffusivity (ft2/sec)	0.000098
Influent Concentration (ug/l)	300
Required Effluent Concentration (ug/l)	7
Henrys Law Constant (atm)	461

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	34

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	41
Overall Mass Transfer Coefficient - kla (1/hr)	26
Overall Coefficient w/Adjust Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	3.8
Height of Transfer Unit - HTU (ft)	4.5
Required Packing Depth (ft)	17
Packing Volume (ft3)	1944

TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (TCE)

Contaminant Properties

Contaminant Name	TCE
Adjustment Factor (percent)	45
Liquid Phase Diffusivity (ft2/sec)	0.0000000075
Gas Phase Diffusivity (ft2/sec)	0.0000853
Influent Concentration (ug/l)	25
Required Effluent Concentration (ug/l)	5
Henrys Law Constant (atm)	247

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	18

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	37
Overall Mass Transfer Coefficient - kla (1/hr)	23
Overall Coefficient w/Adjust Factor - kla' (1/hr)	12
Number of Transfer Units - NTU (transfer units)	1.7
Height of Transfer Unit - HTU (ft)	5.7
Required Packing Depth (ft)	9
Packing Volume (ft3)	1072

TABLE C-14
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 9 - AVERAGE FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (PCE)

Contaminant Properties

Contaminant Name	PCE
Adjustment Factor (percent)	50
Liquid Phase Diffusivity (ft2/sec)	0.0000000068
Gas Phase Diffusivity (ft2/sec)	0.0000768
Influent Concentration (ug/l)	2.9
Required Effluent Concentration (ug/l)	0.7
Henrys Law Constant (atm)	647

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	48

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	35
Overall Mass Transfer Coefficient - kla (1/hr)	24
Overall Coefficient w/Safety Factor - kla' (1/hr)	12
Number of Transfer Units - NTU (transfer units)	1.4
Height of Transfer Unit - HTU (ft)	5.8
Required Packing Depth (ft)	8
Packing Volume (ft3)	947

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TABLE C-15
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 10 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed In This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	1,300
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.09

TABLE C-15
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 10 - AVERAGE FLOW, PEAK MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.77
Gas Volumetric Loading Rate (cfm/ft2)	266
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.33
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	77
Overall Mass Transfer Coefficient - kla (1/hr)	33
Overall Coefficient w/Adjust Factor - kla' (1/hr)	23
Number of Transfer Units - NTU (transfer units)	7.6
Height of Transfer Unit - HTU (ft)	6.8
Required Packing Depth (ft)	52
Packing Volume (ft3)	2617

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	4.69
Blower Power (hp)	31
Pump Power (hp)	18
Total Power Requirement (hp)	49

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TABLE C-16
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 11 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	120

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	1,300
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.125

TABLE C-16
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 11 - AVERAGE FLOW, PEAK MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.77
Gas Volumetric Loading Rate (cfm/ft2)	319
Gas Flow Rate (cfm)	16043
Gas Mass Loading Rate (lb/sec-ft2)	0.40
Stripping Factor - R (dimensionless)	6

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	87
Overall Mass Transfer Coefficient - kla (1/hr)	35
Overall Coefficient w/Adjust Factor - kla' (1/hr)	25
Number of Transfer Units - NTU (transfer units)	7.3
Height of Transfer Unit - HTU (ft)	6.5
Required Packing Depth (ft)	48
Packing Volume (ft3)	2394

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	5.96
Blower Power (hp)	47
Pump Power (hp)	17
Total Power Requirement (hp)	64

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TABLE C-17
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 12 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	80

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	1,300
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-17
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 12 - AVERAGE FLOW, PEAK MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	136
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.17
Stripping Factor - R (dimensionless)	4

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	48
Overall Mass Transfer Coefficient - kla (1/hr)	21
Overall Coefficient w/Adjust Factor - kla' (1/hr)	15
Number of Transfer Units - NTU (transfer units)	8.1
Height of Transfer Unit - HTU (ft)	6.9
Required Packing Depth (ft)	56
Packing Volume (ft3)	4376

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.11
Blower Power (hp)	6
Pump Power (hp)	19
Total Power Requirement (hp)	25

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TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS (GENERAL)

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

INPUT PARAMETERS (METHYLENE CHLORIDE)

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	1,300
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.028

TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	56
Overall Mass Transfer Coefficient - kla (1/hr)	23
Overall Coefficient w/Adjust Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	7.6
Height of Transfer Unit - HTU (ft)	6.4
Required Packing Depth (ft)	49
Packing Volume (ft3)	3838

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.37
Blower Power (hp)	9
Pump Power (hp)	17
Total Power Requirement (hp)	26

TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS (1,1,1-TCA)

Contaminant Properties

Contaminant Name	1,1,1-TCA
Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000072
Gas Phase Diffusivity (ft2/sec)	0.0000834
Influent Concentration (ug/l)	2500
Required Effluent Concentration (ug/l)	200
Henrys Law Constant (atm)	135

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.028

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	10

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	48
Overall Mass Transfer Coefficient - kla (1/hr)	26
Overall Coefficient w/Adjust Factor - kla' (1/hr)	18
Number of Transfer Units - NTU (transfer units)	2.7
Height of Transfer Unit - HTU (ft)	5.7
Required Packing Depth (ft)	15
Packing Volume (ft3)	1202

TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS (1,1-DCA)

Contaminant Properties

Contaminant Name	1,1-DCA
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000081
Gas Phase Diffusivity (ft2/sec)	0.0000933
Influent Concentration (ug/l)	180
Required Effluent Concentration (ug/l)	4050
Henrys Law Constant (atm)	139

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.028

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	10

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	51
Overall Mass Transfer Coefficient - kla (1/hr)	28
Overall Coefficient w/Adjust Factor - kla' (1/hr)	17
Number of Transfer Units - NTU (transfer units)	-2.2
Height of Transfer Unit - HTU (ft)	6.2
Required Packing Depth (ft)	-14
Packing Volume (ft3)	-1068

TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS (1,1-DCE)

Contaminant Properties

Contaminant Name	1,1-DCE
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000085
Gas Phase Diffusivity (ft2/sec)	0.000098
Influent Concentration (ug/l)	300
Required Effluent Concentration (ug/l)	7
Henrys Law Constant (atm)	461

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.028

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	34

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	53
Overall Mass Transfer Coefficient - kla (1/hr)	35
Overall Coefficient w/Adjust Factor - kla' (1/hr)	21
Number of Transfer Units - NTU (transfer units)	3.8
Height of Transfer Unit - HTU (ft)	4.8
Required Packing Depth (ft)	19
Packing Volume (ft3)	1457

TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS (TCE)

Contaminant Properties

Contaminant Name	TCE
Adjustment Factor (percent)	45
Liquid Phase Diffusivity (ft2/sec)	0.0000000075
Gas Phase Diffusivity (ft2/sec)	0.0000853
Influent Concentration (ug/l)	580
Required Effluent Concentration (ug/l)	5
Henrys Law Constant (atm)	247

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.028

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	18

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	48
Overall Mass Transfer Coefficient - kla (1/hr)	30
Overall Coefficient w/Adjust Factor - kla' (1/hr)	17
Number of Transfer Units - NTU (transfer units)	5.0
Height of Transfer Unit - HTU (ft)	6.1
Required Packing Depth (ft)	31
Packing Volume (ft3)	2395

TABLE C-18
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 13 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS (PCE)

Contaminant Properties

Contaminant Name	PCE
Adjustment Factor (percent)	50
Liquid Phase Diffusivity (ft2/sec)	0.0000000068
Gas Phase Diffusivity (ft2/sec)	0.0000768
Influent Concentration (ug/l)	2.9
Required Effluent Concentration (ug/l)	0.7
Henrys Law Constant (atm)	647

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.028

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	13
Liquid Mass Loading Rate (lb/sec-ft2)	1.77
Gas Volumetric Loading Rate (cfm/ft2)	170
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.21
Stripping Factor - R (dimensionless)	48

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	45
Overall Mass Transfer Coefficient - kla (1/hr)	32
Overall Coefficient w/Safety Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	1.4
Height of Transfer Unit - HTU (ft)	6.3
Required Packing Depth (ft)	9
Packing Volume (ft3)	711

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TABLE C-19
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 14 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS

<u>Variables Analyzed in This Run</u>

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	80

<u>Physical Constants</u>

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

<u>Contaminant Properties</u>

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	1,300
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

<u>Packing Properties</u>

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-19
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 14 - AVERAGE FLOW, PEAK MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	95
Gas Flow Rate (cfm)	10695
Gas Mass Loading Rate (lb/sec-ft2)	0.12
Stripping Factor - R (dimensionless)	4

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	37
Overall Mass Transfer Coefficient - kla (1/hr)	15
Overall Coefficient w/Adjust Factor - kla' (1/hr)	11
Number of Transfer Units - NTU (transfer units)	8.1
Height of Transfer Unit - HTU (ft)	6.6
Required Packing Depth (ft)	53
Packing Volume (ft3)	6036

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.07
Blower Power (hp)	6
Pump Power (hp)	19
Total Power Requirement (hp)	24

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TABLE C-20
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 15 - AVERAGE FLOW, PEAK MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,000
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	1,300
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.02

TABLE C-20
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 15 - AVERAGE FLOW, PEAK MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	9
Liquid Mass Loading Rate (lb/sec-ft2)	1.23
Gas Volumetric Loading Rate (cfm/ft2)	118
Gas Flow Rate (cfm)	13369
Gas Mass Loading Rate (lb/sec-ft2)	0.15
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	16
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	44
Overall Mass Transfer Coefficient - kla (1/hr)	17
Overall Coefficient w/Adjust Factor - kla' (1/hr)	12
Number of Transfer Units - NTU (transfer units)	7.6
Height of Transfer Unit - HTU (ft)	6.1
Required Packing Depth (ft)	47
Packing Volume (ft3)	5276

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	0.93
Blower Power (hp)	6
Pump Power (hp)	16
Total Power Requirement (hp)	22

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TABLE C-21
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 16 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.4

TABLE C-21
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 16 - PEAK FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	32
Liquid Mass Loading Rate (lb/sec-ft2)	4.43
Gas Volumetric Loading Rate (cfm/ft2)	426
Gas Flow Rate (cfm)	21390
Gas Mass Loading Rate (lb/sec-ft2)	0.53
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	23
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	4
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	107
Overall Mass Transfer Coefficient - kla (1/hr)	49
Overall Coefficient w/Adjust Factor - kla' (1/hr)	35
Number of Transfer Units - NTU (transfer units)	6.7
Height of Transfer Unit - HTU (ft)	7.4
Required Packing Depth (ft)	49
Packing Volume (ft3)	2479

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	19.74
Blower Power (hp)	208
Pump Power (hp)	27
Total Power Requirement (hp)	236

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TABLE C-22
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 17 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	8
Air To Water Ratio (Dimensionless)	120

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.6

TABLE C-22
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 17 - PEAK FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	32
Liquid Mass Loading Rate (lb/sec-ft2)	4.43
Gas Volumetric Loading Rate (cfm/ft2)	511
Gas Flow Rate (cfm)	25668
Gas Mass Loading Rate (lb/sec-ft2)	0.64
Stripping Factor - R (dimensionless)	6

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	23
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	4
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	121
Overall Mass Transfer Coefficient - kla (1/hr)	52
Overall Coefficient w/Adjust Factor - kla' (1/hr)	36
Number of Transfer Units - NTU (transfer units)	6.5
Height of Transfer Unit - HTU (ft)	7.0
Required Packing Depth (ft)	45
Packing Volume (ft3)	2276

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	27.19
Blower Power (hp)	344
Pump Power (hp)	25
Total Power Requirement (hp)	370

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TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (GENERAL)

Variables Analyzed In This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	80

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

INPUT PARAMETERS (METHYLENE CHLORIDE)

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.06

TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	218
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	4

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	67
Overall Mass Transfer Coefficient - kla (1/hr)	32
Overall Coefficient w/Adjust Factor - kla' (1/hr)	22
Number of Transfer Units - NTU (transfer units)	7.1
Height of Transfer Unit - HTU (ft)	7.4
Required Packing Depth (ft)	52
Packing Volume (ft3)	4089

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	3.13
Blower Power (hp)	26
Pump Power (hp)	29
Total Power Requirement (hp)	55

TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1,1-TCA)

Contaminant Properties

Contaminant Name	1,1,1-TCA
Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000072
Gas Phase Diffusivity (ft2/sec)	0.0000834
Influent Concentration (ug/l)	1100
Required Effluent Concentration (ug/l)	200
Henrys Law Constant (atm)	135

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.06

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	218
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	8

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	57
Overall Mass Transfer Coefficient - kla (1/hr)	36
Overall Coefficient w/Adjust Factor - kla' (1/hr)	25
Number of Transfer Units - NTU (transfer units)	1.8
Height of Transfer Unit - HTU (ft)	6.5
Required Packing Depth (ft)	12
Packing Volume (ft3)	924

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	0.71
Blower Power (hp)	11
Pump Power (hp)	12
Total Power Requirement (hp)	23

TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1-DCA)

Contaminant Properties

Contaminant Name	1,1-DCA
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000081
Gas Phase Diffusivity (ft2/sec)	0.0000933
Influent Concentration (ug/l)	180
Required Effluent Concentration (ug/l)	4050
Henrys Law Constant (atm)	139

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.06

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	218
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	8

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	61
Overall Mass Transfer Coefficient - kla (1/hr)	39
Overall Coefficient w/Adjust Factor - kla' (1/hr)	23
Number of Transfer Units - NTU (transfer units)	-2.1
Height of Transfer Unit - HTU (ft)	7.0
Required Packing Depth (ft)	-15
Packing Volume (ft3)	-1150

TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (1,1-DCE)

Contaminant Properties

Contaminant Name	1,1-DCE
Adjustment Factor (percent)	40
Liquid Phase Diffusivity (ft2/sec)	0.0000000085
Gas Phase Diffusivity (ft2/sec)	0.000098
Influent Concentration (ug/l)	300
Required Effluent Concentration (ug/l)	7
Henrys Law Constant (atm)	461

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.06

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	218
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	28

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	63
Overall Mass Transfer Coefficient - kla (1/hr)	50
Overall Coefficient w/Adjust Factor - kla' (1/hr)	30
Number of Transfer Units - NTU (transfer units)	3.9
Height of Transfer Unit - HTU (ft)	5.4
Required Packing Depth (ft)	21
Packing Volume (ft3)	1648

TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (TCE)

Contaminant Properties

Contaminant Name	TCE
Adjustment Factor (percent)	45
Liquid Phase Diffusivity (ft2/sec)	0.0000000075
Gas Phase Diffusivity (ft2/sec)	0.0000853
Influent Concentration (ug/l)	580
Required Effluent Concentration (ug/l)	5
Henrys Law Constant (atm)	247

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.06

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	218
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	15

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	57
Overall Mass Transfer Coefficient - kla (1/hr)	43
Overall Coefficient w/Adjust Factor - kla' (1/hr)	24
Number of Transfer Units - NTU (transfer units)	5.0
Height of Transfer Unit - HTU (ft)	6.9
Required Packing Depth (ft)	35
Packing Volume (ft3)	2738

TABLE C-23
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 18 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS (PCE)

Contaminant Properties

Contaminant Name	PCE
Adjustment Factor (percent)	50
Liquid Phase Diffusivity (ft2/sec)	0.0000000068
Gas Phase Diffusivity (ft2/sec)	0.0000768
Influent Concentration (ug/l)	2.9
Required Effluent Concentration (ug/l)	0.7
Henrys Law Constant (atm)	647

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.06

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	218
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.27
Stripping Factor - R (dimensionless)	39

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	54
Overall Mass Transfer Coefficient - kla (1/hr)	46
Overall Coefficient w/Safety Factor - kla' (1/hr)	23
Number of Transfer Units - NTU (transfer units)	1.4
Height of Transfer Unit - HTU (ft)	7.1
Required Packing Depth (ft)	10
Packing Volume (ft3)	801

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TABLE C-24
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 19 - PEAK FLOW, AVERAGE MC CONCENTRATION, 3.5 INCH TRIPAC

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.1

TABLE C-24
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 19 - PEAK FLOW, AVERAGE MC CONCENTRATION, 3.5 INCH TRIPAC

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	272
Gas Flow Rate (cfm)	21390
Gas Mass Loading Rate (lb/sec-ft2)	0.34
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	78
Overall Mass Transfer Coefficient - kla (1/hr)	34
Overall Coefficient w/Adjust Factor - kla' (1/hr)	24
Number of Transfer Units - NTU (transfer units)	6.7
Height of Transfer Unit - HTU (ft)	6.9
Required Packing Depth (ft)	46
Packing Volume (ft3)	3606

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	4.59
Blower Power (hp)	48
Pump Power (hp)	26
Total Power Requirement (hp)	74

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TABLE C-25
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 20 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed In This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	10
Air To Water Ratio (Dimensionless)	120

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.14

TABLE C-25
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 20 - PEAK FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	20
Liquid Mass Loading Rate (lb/sec-ft2)	2.83
Gas Volumetric Loading Rate (cfm/ft2)	327
Gas Flow Rate (cfm)	25668
Gas Mass Loading Rate (lb/sec-ft2)	0.41
Stripping Factor - R (dimensionless)	6

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	20
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	3
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	89
Overall Mass Transfer Coefficient - kla (1/hr)	36
Overall Coefficient w/Adjust Factor - kla' (1/hr)	25
Number of Transfer Units - NTU (transfer units)	6.5
Height of Transfer Unit - HTU (ft)	6.5
Required Packing Depth (ft)	42
Packing Volume (ft3)	3302

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	5.89
Blower Power (hp)	75
Pump Power (hp)	23
Total Power Requirement (hp)	98

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TABLE C-26
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 21 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	80

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.025

TABLE C-26
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 21 - PEAK FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	14
Liquid Mass Loading Rate (lb/sec-ft2)	1.97
Gas Volumetric Loading Rate (cfm/ft2)	151
Gas Flow Rate (cfm)	17112
Gas Mass Loading Rate (lb/sec-ft2)	0.19
Stripping Factor - R (dimensionless)	4

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	52
Overall Mass Transfer Coefficient - kla (1/hr)	23
Overall Coefficient w/Adjust Factor - kla' (1/hr)	16
Number of Transfer Units - NTU (transfer units)	7.1
Height of Transfer Unit - HTU (ft)	7.0
Required Packing Depth (ft)	50
Packing Volume (ft3)	5602

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.24
Blower Power (hp)	10
Pump Power (hp)	28
Total Power Requirement (hp)	38

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TABLE C-27
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 22 - PEAK FLOW, AVERAGE MC CONCENTRATION

INPUT PARAMETERS

Variables Analyzed in This Run

Water Flow Rate (gpm)	1,600
Tower Diameter (ft)	12
Air To Water Ratio (Dimensionless)	100

Physical Constants

Liquid Temp (Degrees K)	283
Liquid Density (lb/ft3)	62.4
Liquid Viscosity (lb/ft-sec)	0.00088
Liquid Surface Tension (lb/sec2)	0.164
Gas Density (lb/ft3)	0.0752
Gas Viscosity (lb/ft-sec)	0.00001

Contaminant Properties

Contaminant Name	Methylene Chloride
Kla Adjustment Factor (percent)	30
Liquid Phase Diffusivity (ft2/sec)	0.0000000096
Gas Phase Diffusivity (ft2/sec)	0.000107
Influent Concentration (ug/l)	625
Required Effluent Concentration (ug/l)	2.5
Henrys Law Constant (atm)	64

Packing Properties

Name	Jaeger Tripacks
Diameter (inches)	3.5
Specific Area (ft2/ft3)	38
Surface Tension (lb/sec2)	0.0727
Pressure Drop (inches H2O/ft packing)	0.035

TABLE C-27
AIR STRIPPING TOWER ANALYSIS PROGRAM
FOR COLBERT LANDFILL
DESIGN RUN 22 - PEAK FLOW, AVERAGE MC CONCENTRATION

CALCULATED PARAMETERS

Loading Rates

Liquid Volumetric Loading Rate (gpm/ft2)	14
Liquid Mass Loading Rate (lb/sec-ft2)	1.97
Gas Volumetric Loading Rate (cfm/ft2)	189
Gas Flow Rate (cfm)	21390
Gas Mass Loading Rate (lb/sec-ft2)	0.24
Stripping Factor - R (dimensionless)	5

Mass Transfer Parameters

Specific Wetted Area of Packing - aw (ft2/ft3)	18
Liquid Phase Mass Transfer Coefficient - kl (ft/hr)	2
Gas Phase Mass Transfer Coefficient - kg (ft/hr)	61
Overall Mass Transfer Coefficient - kla (1/hr)	25
Overall Coefficient w/Adjust Factor - kla' (1/hr)	17
Number of Transfer Units - NTU (transfer units)	6.7
Height of Transfer Unit - HTU (ft)	6.5
Required Packing Depth (ft)	44
Packing Volume (ft3)	4925

Energy Factors

Total Air Pressure Drop in Packing (inches H2O)	1.52
Blower Power (hp)	16
Pump Power (hp)	24
Total Power Requirement (hp)	40

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